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(71) Applicant *(for all designated States except US)*: **YALE UNIVERSITY** [US/US]; 451 College Street, New Haven, CT 06510 (US).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **MEDZHITOV, Ruslan, M. PH., D.** [US/US]; 310 Cedar Street, New Haven, CT 06520-08011 (US).

(74) Agent: **HALLIDAY, Christopher, I.**; Morgan, Lewis & Bockius LLP, 1701 Market Street, Philadelphia, PA 19103 (US).

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(54) Title: INNATE IMMUNE SYSTEM-DIRECTED VACCINES

(57) Abstract: The present invention provides novel vaccines, method for the production of such vaccines and methods of using such vaccines. The novel vaccines of the present invention combine both of the signals necessary to activate native T-cells - specific antigen and the co-stimulatory signal - leading to a robust and specific T-cell immune response.

INNATE IMMUNE SYSTEM-DIRECTED VACCINES

FIELD OF THE INVENTION

The present invention relates to novel vaccines, the production of such vaccines and methods of using such vaccines. More specifically, this invention provides unique vaccine molecules comprising an isolated Pathogen Associated Molecular Pattern (PAMP) and an antigen. Even more specifically, this invention provides novel fusion proteins comprising an isolated PAMP and an antigen such that vaccination with these fusion proteins provides the two signals required for native T-cell activation. The novel vaccines of the present invention provide an efficient way of making and using a single molecule to induce a robust T-cell immune response that activates other aspects of the adaptive immune responses. The methods and compositions of the present invention provide a powerful way of designing, producing and using vaccines targeted to specific antigens, including antigens associated with selected pathogens, tumors, allergens and other disease-related molecules.

BACKGROUND OF THE INVENTION

All articles, patents and other materials referred to below are specifically incorporated herein by reference.

1. Immunity

Multicellular organisms have developed two general systems of immunity to infectious agents. The two systems are innate or natural immunity (also known as "innate immunity") and adaptive (acquired) or specific immunity. The major difference between the two systems is the mechanism by which they recognize infectious agents.

The innate immune system uses a set of germline-encoded receptors for the recognition of conserved molecular patterns present in microorganisms. These molecular patterns occur in certain constituents of microorganisms including: lipopolysaccharides, peptidoglycans, lipoteichoic acids, phosphatidyl cholines, bacteria-specific proteins, including lipoproteins, bacterial DNAs, viral single and double-stranded RNAs, unmethylated CpG-DNAs, mannans and a variety of other bacterial and fungal cell wall components. Such molecular patterns can also occur in other molecules such as plant alkaloids. These targets of innate immune recognition are called Pathogen Associated Molecular Patterns (PAMPs) since they are produced by microorganisms and not by the infected host organism. (Janeway *et al.* (1989) *Cold Spring Harb. Symp. Quant. Biol.* 54: 1-13; Medzhitov *et al.* (1997) *Curr. Opin. Immunol.* 94: 4-9).

The receptors of the innate immune system that recognize PAMPs are called Pattern Recognition Receptors (PRRs). (Janeway *et al.* (1989) *Cold Spring Harb. Symp. Quant. Biol.* 54: 1-13; Medzhitov *et al.* (1997) *Curr. Opin. Immunol.* 94: 4-9). These receptors vary in structure and belong to several different protein families. Some of these receptors recognize PAMPs directly (*e.g.*, CD14, DEC205, collectins), while others (*e.g.*, complement receptors) recognize the products generated by PAMP recognition. Members of these receptor families can, generally, be divided into three types: 1) humoral receptors circulating in the plasma; 2) endocytic receptors expressed on immune-cell surfaces, and 3) signaling receptors that can be expressed either on the cell surface or intracellularly. (Medzhitov *et al.* (1997) *Curr. Opin. Immunol.* 94: 4-9; Fearon *et al.* (1996) *Science* 272: 50-3).

Cellular PRRs are expressed on effector cells of the innate immune system, including cells that function as professional antigen-presenting cells (APC) in adaptive immunity. Such effector cells include, but are not limited to, macrophages, dendritic cells, B lymphocytes and surface epithelia. This expression profile allows PRRs to directly induce innate effector mechanisms, and also to alert the host organism to the presence of infectious agents by inducing the expression of a set of endogenous signals, such as inflammatory cytokines and chemokines, as discussed below. This latter function allows efficient mobilization of effector forces to combat the invaders.

In contrast, the adaptive immune system, which is found only in vertebrates, uses two types of antigen receptors that are generated by somatic mechanisms during the development of each individual organism. The two types of antigen receptors are the T-cell receptor (TCR) and the immunoglobulin receptor (IgR), which are expressed on two specialized cell types, T-lymphocytes and B-lymphocytes, respectively. The specificities of these antigen receptors are generated at random during the maturation of lymphocytes by the processes of somatic gene rearrangement, random pairing of receptor subunits, and by a template-independent addition of nucleotides to the coding regions during the rearrangement.

Recent studies have demonstrated that the innate immune system plays a crucial role in the control of initiation of the adaptive immune response and in the induction of appropriate cell effector responses. (Fearon *et al.* (1996) *Science* 272: 50-3; Medzhitov *et al.* (1997) *Cell* 91: 295-8). Indeed, it is now well established that the activation of naive T-lymphocytes requires two distinct signals: one is a specific

antigenic peptide recognized by the TCR, and the other is the so called co-stimulatory signal, B7, which is expressed on APCs and recognized by the CD28 molecule expressed on T-cells. (Lenschow *et al.* (1996) *Annu. Rev. Immunol.* 14: 233-58). Activation of naive $CD4^+$ T-lymphocytes requires that both signals, the specific antigen and the B7 molecule, are expressed on the same APC. If a naive CD4 T-cell recognizes the antigen in the absence of the B7 signal, the T-cell will die by apoptosis. Expression of B7 molecules on APCs, therefore, controls whether or not the naive CD4 T-lymphocytes will be activated. Since CD4 T-cells control the activation of CD8 T-cells for cytotoxic functions, and the activation of B-cells for antibody production, the expression of B7 molecules determines whether or not an adaptive immune response will be activated.

Recent studies have also demonstrated that the innate immune system plays a crucial role in the control of B7 expression. (Fearon *et al.* (1996) *Science* 272: 50-3; Medzhitov *et al.* (1997) *Cell* 91: 295-8). As mentioned earlier, innate immune recognition is mediated by PRRs that recognize PAMPs. Recognition of PAMPs by PRRs results in the activation of signaling pathways that control the expression of a variety of inducible immune response genes, including the genes that encode signals necessary for the activation of lymphocytes, such as B7, cytokines and chemokines. (Medzhitov *et al.* (1997) *Cell* 91: 295-8; Medzhitov *et al.* (1997) *Nature* 388: 394-397). Induction of B7 expression by PRR upon recognition of PAMPs thus accounts for self/nonself discrimination and ensures that only T-cells specific for microorganism-derived antigens are normally activated. This mechanism normally prevents activation of autoreactive lymphocytes specific for self-antigens.

Receptors of the innate immune system that control the expression of B7 molecules and cytokines have recently been identified. (Medzhitov *et al.* (1997) *Nature* 388: 394-397; Rock *et al.* (1998) *Proc. Natl. Acad. Sci. U S A*, 95: 588-93). These receptors belong to the family of Toll-like receptors (TLRs), so called because they are homologous to the *Drosophila* Toll protein which is involved both in dorsoventral patterning in *Drosophila* embryos and in the immune response in adult flies. (Lemaitre *et al.* (1996) *Cell* 86: 973-83). In mammalian organisms, such TLRs have been shown to recognize PAMPs such as the bacterial products LPS, peptidoglycan, and lipoprotein. (Schwandner *et al. (1999) J. Biol. Chem.* 274: 17406-9; Yoshimura *et al.* (1999) J. *Immunol.* 163: 1-5; Aliprantis *et al.* (1999) *Science* 285: 736-9).

2. Vaccine Development

Vaccines have traditionally been used as a means to protect against disease caused by infectious agents. However, with the advancement of vaccine technology, vaccines have been used in additional applications that include, but are not limited to, control of mammalian fertility, modulation of hormone action, and prevention or treatment of tumors.

The primary purpose of vaccines used to protect against a disease is to induce immunological memory to a particular microorganism. More generally, vaccines are needed to induce an immune response to specific antigens, whether they belong to a microorganism or are expressed by tumor cells or other diseased or abnormal cells. Division and differentiation of B- and T-lymphocytes that have surface receptors specific for the antigen generate both specificity and memory.

In order for a vaccine to induce a protective immune response, it must fulfill the following requirements: 1) it must include the specific antigen(s) or fragment(s) thereof that will be the target of protective immunity following vaccination; 2) it must present such antigens in a form that can be recognized by the immune system, *e.g.*, a form resistant to degradation prior to immune recognition; and 3) it must activate APCs to present the antigen to $CD4^+$ T-cells, which in turn induce B-cell differentiation and other immune effector functions.

Conventional vaccines contain suspensions of attenuated or killed microorganisms, such as viruses or bacteria, incapable of inducing severe infection by themselves, but capable of counteracting the unmodified (or virulent) species when inoculated into a host. Usage of the term has now been extended to include essentially any preparation intended for active immunologic prophylaxis (*e.g.*, preparations of killed microbes of virulent strains or living microbes of attenuated (variant or mutant) strains; microbial, fungal, plant, protozoan, or metazoan derivatives or products; synthetic vaccines). Examples of vaccines include, but are not limited to, cowpox virus for inoculating against smallpox, tetanus toxoid to prevent tetanus, whole-inactivated bacteria to prevent whooping cough (pertussis), polysaccharide subunits to prevent streptococcal pneumonia, and recombinant proteins to prevent hepatitis B.

Although attenuated vaccines are usually immunogenic, their use has been limited because their efficacy generally requires specific, detailed knowledge of the molecular determinants of virulence. Moreover, the use of attenuated pathogens in

vaccines is associated with a variety of risk factors that in most cases prevent their safe use in humans.

The problem with synthetic vaccines, on the other hand, is that they are often non-immunogenic or non-protective. The use of available adjuvants to increase the immunogenicity of synthetic vaccines is often not an option because of unacceptable side effects induced by the adjuvants themselves.

An adjuvant is defined as any substance that increases the immunogenicity of admixed antigens. Although chemicals such as alum are often considered to be adjuvants, they are in effect akin to carriers and are likely to act by stabilizing antigens and/or promoting their interaction with antigen-presenting cells. The best adjuvants are those that mimic the ability of microorganisms to activate the innate immune system. Pure antigens do not induce an immune response because they fail to induce the costimulatory signal (*e.g.*, B7.1 or B7.2) necessary for activation of lymphocytes. Thus, a key mechanism of adjuvant activity has been attributed to the induction of costimulatory signals by microbial, or microbial-like, constituents carrying PAMPs that are routine constituents of adjuvants. (Janeway *et al.* (1989) *Cold Spring Harb. Symp. Quant. Biol.*, 54: 1-13). As discussed above, the recognition of these PAMPs by PRRs induces the signals necessary for lymphocyte activation (such as B7) and differentiation (effector cytokines).

Because adjuvants are often used in molar excess of antigens and thus trigger an innate immune response in many cells that do not come in contact with the target antigen, this non-specific induction of the innate immune system to produce the signals that are required for activation of an adaptive immune response produces an

excessive inflammatory response that renders many of the most potent adjuvants clinically unsuitable. Alum is currently approved for use as a clinical adjuvant, even though it has relatively limited efficacy, because it is not an innate immune stimulant and thus does not cause excessive inflammation. However, a vaccine that included the use of an innate immune stimulant in such a way as not to elicit excess inflammation could be far more effective than vaccines comprising an antigen together with an adjuvant such as alum. Fusion of an antigen with a PAMP, such as bacterial lipoprotein (BLP), optimizes the stoichiometry of the two signals and coordinates their effect on the same APC, thus minimizing the unwanted excessive inflammatory responses that occur when antigens are mixed with adjuvants comprising innate immune stimulants to increase their immunogenicity. In addition, the chimeric constructs of the present invention will prevent activation of APCs that do not take up the antigen. Activation of such APCs in the absence of uptake and presentation of the target antigen can lead to the induction of autoimmune responses, which, again, is one of the problems with commonly used innate immunity-stimulating adjuvants that prevents or limits their use in humans. Notably, the chimeric constructs of the present invention exhibit the essential immunological characteristics or properties expected of a conventional vaccine supplemented with an adjuvant, but the chimeric constructs do not induce an excessive inflammatory reaction as is often induced by an adjuvant. Thus, the vaccine approach described in the present invention minimizes or eliminates undesired side effects (*e.g.*, excessive inflammatory reaction, autoimmunity) yet induces a very potent and specific immune

response, and provides a favorable alternative to vaccines comprising mixtures of antigens and adjuvants.

3. Alternative Vaccine Strategies

Immune Stimulating Complexes for Use as Vaccines. Immune stimulating complexes (ISCOMS) are cage-like structures comprising Quil-A, cholesterol, adjuvant active saponin and phospholipids that induce a wide range of systemic immune responses. (Mowat *et al.* (1999) *Immunol. Lett.* 65: 133-140; Smith *et al.*, (1999) *J. Immunol.* 162(9): 5536-5546). ISCOMS are suitable for repeated administration of different antigens to an individual because these complexes allow the entry of antigen into both MHC I and II processing pathways. (Mowat *et al.* (1991) *Immunol.* 72: 317-322).

ISCOMS have been used with conjugates of modified soluble proteins. (Reid (1992) *Vaccine* 10(9): 597-602). These complexes also produce a Th1 type response, as would be expected for such a vaccine. (Morein *et al.* (1999) *Methods* 19: 94-102).

However, in contrast to the molecules of the present invention, ISCOMS are far more complex structures that present potential problems of reproducibility and dosing; nor do they contain conjugates between an antigen and a PAMP. Since ISCOMS do not specifically target APCs their use can result in problems of toxicity and a lack of specificity.

Multiple Antigenic Recombinant Vaccines. Various U.S. patents disclose chimeric proteins consisting of multiple antigenic peptides (MAPs) for use as vaccines. For example, Klein *et al.* were granted a family of patents (*e.g.*, U.S. Patent

No. 6,033,668; 6,017,539; 5,998,169; and 5,968,776) which describe genes encoding multimeric hybrids comprising an immunogenic region of a protein from a first antigen linked to an immunogenic region from a second pathogen. While the patents are focused on human Parainfluenza/Respiratory syncytial virus protein chimeras, the first and second antigens may be more broadly selected from bacterial and viral pathogens. Although the vaccines contemplated by Klein et al. are fusion proteins, all the component peptides are all selected by virtue of their being antigens (i.e., being recognized by a TCR or IgR) rather than a pairing of antigens with PAMPs, and thus the vaccines are not designed to stimulate the innate immune system.

Sinugalia (U.S. Patent No. 5,114,713) discloses vaccines consisting of peptides from the circumsporozoite protein of *Plasmodium falciparum* (*P. falciparum*) as universal T-cell epitopes that can be coupled to B-cell epitopes, such as surface proteins derived from pathogenic agents *(e.g.,* bacteria, viruses, fungi or parasites). These combined peptides can be prepared by recombinant means. These universal T-cell epitopes are not known to be PAMPs, and they act via the adaptive immune system rather than the innate immune system.

Russell-Jones *et al.* (U.S. Patent No. 5,928,644) disclose T-cell epitopes derived from the TraT protein of *E. coli* that is used to produce hybrid molecules to raise immune responses against various targets to include parasites, soluble factors (*e.g.*, LSH) and viruses. Thus, these constructs provide strategies for increasing the complexity of the antigenic nature of the vaccines, thereby promoting strengthened or multiple adaptive immune responses. However, the epitopes are not known to be

PAMPs, and they act via the adaptive immune system rather than the innate immune system.

Thus, the aforementioned inventions are very different in intent, concept, strategy and mode of action from the present invention.

4. Overview of the Novel Vaccines of the Present Invention

The novel vaccines of the present invention comprise one or more isolated PAMPs in combination with one or more antigens. The antigens used in the vaccines of the present invention can be any type of antigen (*e.g.*, including but not limited to pathogen-related antigens, tumor-related antigens, allergy-related antigens, neural defect-related antigens, cardiovascular disease antigens, rheumatoid arthritis-related antigens, other disease-related antigens, hormones, pregnancy-related antigens, embryonic antigens and/or fetal antigens and the like). Examples of various types of vaccines, which can be produced by the present invention, are provided in Figure 1.

In one preferred embodiment, the vaccines are recombinant proteins, or recombinant lipoproteins, or recombinant glycoproteins, which contain a PAMP (*e.g.*, BLP or Flagellin) and one or more antigens. The basic concept for preparing a fusion protein of the present invention is provided in Figure 1.

Upon administration into human or animal subjects, the vaccines of the present invention will interact with APCs, such as dendritic cells and macrophages. This interaction will have two consequences: First, the PAMP portion of the vaccine will interact with a PRR such as a TLR and stimulate a signaling pathway, such as the NF-κB, JNK and/or p38 pathways. Second, due to the PAMP's interaction with TLRs and/or other pattern-recognition receptors, the recombinant vaccine will be

taken up into dendritic cells and macrophages by phagocytosis, endocytosis, or macropinocytosis, depending on the cell type, the size of the recombinant vaccine, and the identity of the PAMP.

Activation of TLR-induced signaling pathways will lead to the induction of the expression of cytokines, chemokines, adhesion molecules, and co-stimulatory molecules by dendritic cells and macrophages and, in some cases, B-cells. Uptake of the vaccines will lead to the processing of the antigen(s) fused to the PAMP and their presentation by the MHC class-I and MHC class-II molecules. This will generate the two signals required for the activation of naive T-cells – a specific antigen signal and the co-stimulatory signal. In addition, chemokines induced by the vaccine (due to PAMP interaction with TLR) will recruit naive T-cells to the APC and cytokines, like IL-12, which will induce T-cell differentiation into Th-1 effector cells. As a result, a robust T-cell immune response will be induced, which will in turn activate other aspects of the adaptive immune responses, such as activation of antigen-specific B-cells and macrophages.

Thus, the novel vaccines of the present invention provide an efficient way to produce an immune response to one or more specific antigens without the adverse side effects normally associated with conventional vaccines.

SUMMARY OF THE INVENTION

The present invention relates generally to vaccines, methods of making vaccines and methods of using vaccines.

More specifically, the present invention provides vaccines comprising an isolated PAMP, immunostimulatory portion or immunostimulatory derivative thereof

and an antigen or an immunogenic portion or immunogenic derivative thereof. An example of a preferred vaccine of the present invention is a fusion protein comprising a PAMP, immunostimulatory portion or immunostimulatory derivative thereof and an antigen or an immunogenic portion or immunogenic derivative thereof.

The vaccines of the present invention can comprise any PAMP peptide or protein, including, but not limited to, the following PAMPs: peptidoglycans, lipoproteins and lipopeptides, Flagellins, outer membrane proteins (OMPs), outer surface proteins (OSPs), other protein components of the bacterial cell walls, and other PRR ligands.

One preferred PAMP of the present invention is BLP, including the BLP encoded by the polypeptide of SEQ ID NO: 2, set forth in Figure 15. In addition to protein PAMPs, also useful in the vaccines of the present invention are peptide mimetics of any non-protein PAMP.

Antigens useful in the present invention include, but are not limited to, those that are microorganism-related, and other disease-related antigens, including but not limited to those that are allergen-related and cancer-related. The antigen component of the vaccine can be derived from sources that include, but are not limited to, bacteria, viruses, fungi, yeast, protozoa, metazoa, tumors, malignant cells, plants, animals, humans, allergens, hormones and amyloid-β peptide. The antigens, immunogenic portions or immunogenic derivatives thereof can be composed of peptides, polypeptides, lipoproteins, glycoproteins, mucoproteins and the like.

The various vaccines of the present invention include, but are not limited to:

1) one or more PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, conjugated to one or more antigens, immunogenic portions or immunogenic derivatives thereof;

2) a PAMP/antigen fusion protein comprising one or more PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, and one or more antigens, immunogenic portions or immunogenic derivatives thereof; and

3) a modified antigen, immunogenic portion or immunogenic derivative thereof, that comprises a leader sequence fused to a lipidation or glycosylation consensus sequence that is further fused to the antigen, or an immunogenic portion or immunogenic derivative thereof.

The present invention also encompasses such vaccines further comprising a pharmaceutically acceptable carrier, including, but not limited to, alum.

More specifically, the present invention provides fusion proteins comprising one or more PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, and one or more antigens, immunogenic portions or immunogenic derivatives thereof. The PAMP domains of the fusion proteins of the present invention can be composed of amino acids, amino acid polymers, peptidoglycans, glycoproteins, and lipoproteins or any other suitable component. One preferred PAMP to use in the fusion proteins of the present invention is BLP, including the BLP encoded by the polypeptide of SEQ ID NO: 2. Flagellin is another PAMP to use in the fusion proteins of the present invention, and is provided by (but not limited to) accession numbers P04949 (E. Coli Flagellin) and A24262 (Salmonella Flagellin). Useful antigen domain(s) in the fusion proteins of the present invention include, but are not

limited to, Eα (a peptide antigen derived from mouse MHC class-II I-E), listeriolysin, PSMA, HIV gp120, Ra5G and TRP-2. In one preferred embodiment, the fusion proteins of the present invention include a construct comprising the following components: a leader peptide that signals lipidation or glycosylation of the consensus sequence, a lipidation and/or glycosylation consensus sequence, and antigen. More specifically, the fusion proteins of the present invention include a construct comprising a leader sequence—CXXN—antigen, wherein the leader peptide is a signal for lipidation of the consensus sequence and wherein X is any amino acid, preferably serine. Examples of leader peptides useful in the present invention include, but are not limited to, those selected from the peptides of SEQ ID NO: 3 (shown in Figure 15), SEQ ID NO: 4 (shown in Figure 16), SEQ ID NO: 5 (shown in Figure 17), SEQ ID NO: 6 (shown in Figure 18) and SEQ ID NO: 7 (shown in Figure 19).

In another embodiment, the present invention provides also provides a fusion protein comprising an isolated PAMP and an antigen, wherein the antigen is a self-antigen.

The present invention further provides methods of recombinantly producing the fusion proteins of the present invention. Thus, the present invention provides recombinant expression vectors comprising a nucleotide sequence encoding the chimeric constructs of the present invention as well as host cells transformed with such recombinant expression vectors. Any cell that is capable of expressing the fusion proteins of the present invention is suitable for use as a host cell. Such host cells include, but are not limited to, the cells of bacteria, yeast, insects, plants and animals. More preferably for certain PAMPs such as BLP, the host cell is a bacterial

cell. Even more preferably, the host cell is a bacterial cell that can appropriately modify (*e.g.*, lipidation, glycosylation) the PAMP domain of the fusion protein when such modification is necessary or desirable.

The present invention also provides methods of immunizing an animal with the vaccines of the present invention, where such methods include, but are not limited to, administering a vaccine parenterally, intravenously, orally, using suppositories, or via the mucosal surfaces. In one preferred embodiment the animal being vaccinated is a human.

The immune response can be measured using any suitable method including, but not limited to, direct measurement of peripheral blood lymphocytes, natural killer cell cytotoxicity assays, cell proliferation assays, immunoassays of immune cells and subsets, and skin tests for cell-mediated immunity.

The present invention also provides methods of treating a patient susceptible to an allergic response to an allergen by administering a vaccine of the present invention and thereby stimulating the TLR-mediated signaling pathway.

The present invention also provides methods of treating a patient susceptible to or suffering from Alzheimer's disease by administering a vaccine of the present invention in which the target antigen is a peptide or protein associated with Alzheimer's disease, including but not limited to amyloid- peptide.

The present invention further provides a method of stimulating an innate immune response in an animal and thereby enhancing the adaptive immune response to a foreign or self-antigen which comprises co-administering a PAMP with the foreign or self antigen.

The present invention also provides a vaccine which comprises a PAMP conjugated with a foreign or self antigen that stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

Additionally, the present invention provides a vaccine which comprises a PAMP conjugated with a foreign or self antigen which, when administered at a therapeutically active dose, stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

The present invention also provides a method of treatment comprising the steps of administering to an individual a vaccine which comprises a PAMP conjugated with a foreign or self antigen which stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

Additional embodiments of the present invention will be obvious to those skilled in the art of vaccine preparation and vaccine administration. Such obvious variations of the present invention are also contemplated by the present inventor.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows examples of alternative fusion proteins according to the present invention. Permutations and combinations of these fusion proteins can also be prepared according to the methods of the present invention.

Figure 2 shows a basic outline for generating different recombinant protein vaccines containing different antigens and a signal to trigger the innate immune response (PAMP). Each antigen is represented by a different shape of the central portion of the vaccine.

Figure 3 shows the BLP/Eα construct.

Figure 4 shows that BLP/Eα activates NF-κB in dose-dependent manner.

Figure 5 shows IL-6 production by dendritic cells stimulated with BLP/Eα.

Figure 6 shows the induction of dendritic cell activation and vaccine antigen processing and presentation by the MHC class-II pathway.

Figure 7 shows the immunostimulatory effect of the chimeric construct BLP/Eα on specific T-cells *in vitro*.

Figure 8 shows the effect of the chimeric construct, BLP/Eα, on specific T-cell proliferation *in vivo*.

Figure 9 shows that CpG-induced B-cell activation is dependent upon MyD88. MyD88 $^{-/-}$, MyD88-deficient cells; ICE $^{-/-}$, caspase-1-deficient cells; B10/ScCr, TLR4-deficient cells derived from C57BL/10ScCr mice; TLR2 $^{-/-}$, TLR2-deficient cells.

Figure 10 shows that IL-6 production by macrophages during CpG stimulation and CpG-DNA-induced IkBα degradation is mediated by a signaling pathway dependent on MyD88.

Figure 11 shows that wild-type and B10/ScCr dendritic cells, but not dendritic cells from MyD88$^{-/-}$ animals produce IL-12 when stimulated with CpG oligonucleotides.

Figure 12 shows activation of NF-κB by Flagellin fusions.

Figure 13 shows induction of NF-κB in macrophages by Flagellin fusions.

Figure 14 shows NF-κB activity in RAW κB cells.

Figure 15 shows SEQ ID NO: 3.

Figure 16 shows SEQ ID NO: 4.

Figure 17 shows SEQ ID NO: 5.

Figure 18 shows SEQ ID NO: 6.

Figure 19 shows SEQ ID NO: 7.

Figure 20 shows SEQ ID NO: 10.

Figure 21 shows SEQ ID NO: 11.

DETAILED DESCRIPTION OF THE INVENTION

1. General Description

The present invention discloses a novel strategy of vaccine design based on the inventor's recent findings in the field of innate immunity. This approach is not limited to any particular antigen or immunogenic portions or derivatives thereof (*e.g.*, microorganism-related, allergen-related or tumor-related, and the like) nor is it limited to any particular PAMP or immunostimulatory portions or immunostimulatory derivatives thereof. The term "vaccine", therefore, is used herein in a general sense to refer to any therapeutic or immunogenic or immunostimulatory composition that includes the features of the present invention. A more detailed definition of vaccine is disclosed elsewhere herein.

The activation of an adaptive immune response requires both the specific antigen or derivative thereof, and a signal (*e.g.* PAMP) that can induce the expression of B7 on the APCs. The present invention combines, in a single chimeric construct, both signals required for the induction of the adaptive immune responses - a signal recognized by the innate immune system (PAMP), and a signal recognized by an antigen receptor (antigen).

According to the present invention, neither the PAMP nor the antigen need consist of a polypeptide. However, either the PAMP or the antigen, or both, may be a peptide or polypeptide. In one embodiment of the present invention, recombinant DNA technology may be utilized in the production of chimeric constructs, for use in vaccines, when both the PAMP, or an immunogenic portion or derivative thereof, and the antigen, or an immunostimulatory portion or derivative thereof, are polypeptides.

Alternatively, recombinant techniques may also be utilized to produce a protein chimeric construct when a peptide mimetic is used in lieu of a non-protein antigen, such as a polysaccharide or a nucleic acid and the like, and/or a non-protein PAMP, such as a lipopolysaccharide, CpG-DNA, bacterial DNA, single or double-stranded viral RNA, phosphatidyl choline, lipoteichoic acids and the like, for example. The present invention contemplates in one embodiment the use of BLP, the bacterial outer membrane proteins (OMP), the outer surface proteins A (OspA) of bacteria, Flagellins and other DNA-encoded PAMPs in the recombinant production of chimeric constructs. These PAMPs are known to induce activation of the innate immune response and therefore would be particularly suitable for use in vaccine formulations. (Henderson *et al.* (1996) *Microbiol. Rev.* 60: 316-41). Furthermore, BLP has been shown to be recognized by TLRs. (Aliprantis *et al.* (1999) *Science* 285: 736-9). The details of the approach are described using BLP as the PAMP domain of a PAMP/antigen fusion protein; however any inducers of the innate immune system are equally applicable for such purpose in the present invention.

In another embodiment, one or more PAMP mimetics is substituted in place of a PAMP in a fusion protein.

This invention further provides methods for producing chimeric constructs where either the PAMP or an immunostimulatory portion or derivative thereof, or the antigen or an immunogenic portion or derivative thereof, or both the PAMP and the antigen are non-protein. Generally, these methods utilize chemical means to conjugate a PAMP to an antigen thereby producing a non-protein chimeric construct.

This invention further provides ways to exploit recombinant DNA technology in the synthesis of the peptide vaccines. Many of the surface antigens present on the pathogens of interest would not be amenable to encoding by nucleic acids as they are not proteins (*e.g.*, lipopolysaccharides) or possess low protein content (*e.g.*, peptidoglycans).

The present invention contemplates the use of peptide mimetics for these surface antigens or an immunogenic protein or derivative thereof, and the use of peptide mimetics in vaccines.

As discussed in greater detail herein, the present invention contemplates vaccines comprising chimeric constructs that comprise at least one antigen, or an immunogenic portion or derivative thereof, and at least one PAMP, or an immunogenic portion or derivative thereof. Thus, the present invention encompasses vaccines comprising fusion proteins where one or more protein antigens are linked to one or more protein PAMPs or a peptide mimetic of a PAMP. Preferably, the fusion protein has maximal immunogenicity and induces only a modest inflammatory response.

In instances in which a target antigen, or a domain of a target antigen, has a relatively low molecular weight and is not adequately immunogenic because of its small size, that antigen or antigen domain can act as a hapten and can be combined with a larger carrier molecule such that the molecular weight of the combined molecule will be high enough to evoke a strong immune response against the antigen. In one embodiment of this invention, the antigen itself serves as the carrier molecule. In another embodiment of this invention, the PAMP serves as the carrier molecule. In

yet another embodiment, a hapten is combined, by either fusion or conjugation, with the PAMP or the antigen domain of the vaccine to elicit an antibody response to the hapten. In yet another embodiment, which would, without limitation, be preferable when the molecular weight of both antigen and PAMP are low, the PAMP and the antigen are combined with a third molecule that serves as the carrier molecule. Such carrier molecule can be keyhole limpet hemocyanin or any of a number of carrier molecules for haptens that are known to the artisan. In yet another embodiment, a fusion protein contains an antigen or antigen domain, a PAMP or a portion of a PAMP or a PAMP mimetic, and a carrier protein or carrier peptide. Once again, such carrier protein can be keyhole limpet hemocyanin or any of a number of carrier proteins or carrier peptides for haptens that are known to the artisan. Increasing the number of antigens or antigen epitopes, by using multiple antigen proteins and/or multiple domains of the same antigen protein or of different antigen proteins and/or some combination of the foregoing, are contemplated in this invention. Also contemplated are fusion proteins in which the number of PAMPs or PAMP derivatives or PAMP mimetics is increased. It is within the skill of the artisan to determine the optimal ratio of PAMP to antigen domains to maximize immunogenicity and minimize inflammatory response.

2. Definitions

"Adaptive immunity" refers to the adaptive immune system, which involves two types of receptors generated by somatic mechanisms during the development of each individual organism. As used herein, the "adaptive immune system" refers to

both cellular and humoral immunity. Immune recognition by the adaptive immune system is mediated by antigen receptors.

"Adaptive immune response" refers to a response involving the characteristics of the "adaptive immune system" described above.

"Adapter molecule" refers to a molecule that can be transiently associated with some TLRs, mediates immunostimulation by molecules of the innate immune system, and mediates cytokine-induced signaling. "Adapter molecule" includes, but is not limited to, myeloid differentiation marker 88 (MyD88).

"Allergen" refers to an antigen, or a portion or derivative of an antigen, that induces an allergic or hypersensitive response.

"Amino acid polymer" refers to proteins, or peptides, and other polymers comprising at least two amino acids linked by a peptide bond(s), wherein such polymers contain either no non-peptide bonds or one or more non-peptide bonds. As used herein, "proteins" include polypeptides and oligopeptides.

"Antigen" refers to a substance that is specifically recognized by the antigen receptors of the adaptive immune system. Thus, as used herein, the term "antigen" includes antigens, derivatives or portions of antigens that are immunogenic and immunogenic molecules derived from antigens. Preferably, the antigens used in the present invention are isolated antigens. Antigens that are particularly useful in the present invention include, but are not limited to, those that are pathogen-related, allergen-related, or disease-related.

"Antigenic determinant" refers to a region on an antigen at which a given antigen receptor binds.

"Antigen-presenting cell" or "APC" or "professional antigen-presenting cell" or "professional APC" is a cell of the immune system that functions in triggering an adaptive immune response by taking up, processing and expressing antigens on its surface. Such effector cells include, but are not limited to, macrophages, dendritic cells and B cells.

"Antigen receptors" refers to the two types of antigen receptors of the adaptive immune system: the T-cell receptor (TCR) and the immunoglobulin receptor (IgR), which are expressed on two specialized cell types, T-lymphocytes and B-lymphocytes, respectively. The secreted form of the immunoglobulin receptor is referred to as antibody. The specificities of the antigen receptors are generated at random during the maturation of the lymphocytes by the processes of somatic gene rearrangement, random pairing of receptor subunits, and by a template-independent addition of nucleotides to the coding regions during the rearrangement.

"Chimeric construct" refers to a construct comprising an antigen and a PAMP, or PAMP mimetic, wherein the antigen and the PAMP are comprised of molecules such as amino acids, amino acid polymers, nucleotides, nucleotide polymers, carbohydrates, carbohydrate polymers, lipids, lipid polymers or other synthetic or naturally occurring chemicals or chemical polymers. As used herein, a "chimeric construct" refers to constructs wherein the antigen is comprised of one type of molecule in association with a PAMP or PAMP mimetic, which is comprised of either the same type of molecule or a different type of molecule.

"CpG" refers to a dinucleotide in which an unmethylated cytosine (C) residue occurs immediately 5' to a guanosine (G) residue. As used herein, "CpG-DNA"

refers to a synthetic CpG repeat, intact bacterial DNA containing CpG motifs, or a CpG-containing derivative thereof. The immunostimulatory effect of CpG-DNA on B-cells is mediated through a TLR and is dependent upon a "protein adapter molecule".

"Derivative" refers to any molecule or compound that is structurally related to the molecule or compound from which it is derived. As used herein, "derivative" includes peptide mimetics (*e.g.*, PAMP mimetics).

"Domain" refers to a portion of a protein with its own function. The combination of domains in a single protein determines its overall function. An "antigen domain" comprises an antigen or an immunogenic portion or derivative of an antigen. A "PAMP domain" comprises a PAMP or a PAMP mimetic or an immunostimulatory portion or derivative of a PAMP or a PAMP mimetic.

"Fusion protein" and "chimeric protein" both refer to any protein fusion comprising two or more domains selected from the following group consisting of: proteins, peptides, lipoproteins, lipopeptides, glycoproteins, glycopeptides, mucoproteins, mucopeptides, such that at least two of the domains are either from different species or encoded by different genes or such that one of the two domains is found in nature and the second domain is not known to be found in nature or such that one of the two domains resembles a molecule found in nature and the other does not resemble that same molecule. The term "fusion protein" also refers to an antigen or an immunogenic portion or derivative thereof which has been modified to contain an amino acid sequence that results in post-translational modification of that amino acid sequence or a portion of that sequence, wherein the post-translationally modified

sequence is a ligand for a PRR. As yet another definition of a fusion protein, in the foregoing sentence, the amino acid sequence that results in post-translational modification to form a ligand for a PRR can comprise a consensus sequence, or that amino acid sequence can contain a leader sequence and a consensus sequence.

"Hapten" refers to a small molecule that is not by itself immunogenic but can bind antigen receptors and can combine with a larger carrier molecule to become immunogenic.

"In association with" refers to a reversible union between two chemical entities, whether alike or different, to form a more complex substance.

"In combination with" refers to either a reversible or irreversible (*e.g.* covalent) union between two chemical entities, whether alike or different, to form a more complex substance.

"Immunostimulatory" refers to the ability of a molecule to activate either the adaptive immune system or the innate immune system. As used herein, "antigens" are examples of molecules that are capable of stimulating the adaptive immune system, whereas PAMPs or PAMP mimetics are examples of molecules that are capable of stimulating the innate immune system. As used herein, "activation" of either immune system includes the production of constituents of humoral and/or cellular immune responses that are reactive against the immunostimulatory molecule.

"Innate immunity" refers to the innate immune system, which, unlike the "adaptive immune system", uses a set of germline-encoded receptors for the recognition of conserved molecular patterns present in microorganisms.

"Innate immune response" refers to a response involving the characteristics of the "innate immune system" described above.

"Isolated" refers to a substance, cell, tissue, or subcellular component that is separated from or substantially purified with respect to a mixture or naturally occurring material.

"Linker" refers to any chemical entity that links one chemical moiety to another chemical moiety. Thus, something that chemically or physically connects a PAMP and an antigen is a linker. Examples of linkers include, but are not limited to, complex or simple hydrocarbons, nucleosides, nucleotides, nucleotide phosphates, oligonucleotides, polynucleotides, nucleic acids, amino acids, small peptides, polypeptides, carbohydrates (*e.g.*, monosaccharides, disaccharides, trisaccharides), and lipids. Additional examples of linkers are provided in the Detailed Description Selection included herein. Without limitation, the present invention also contemplates using a peptide bond or an amino acid or a peptide linker to link a polypeptide PAMP and a polypeptide antigen. The present invention further contemplates preparing such a linked molecule by recombinant DNA procedures. A linker can also function as a spacer.

"Malignant" refers to an invasive, spreading tumor.

"Microorganism" refers to a living organism too small to be seen with the naked eye. Microorganisms include, but are not limited to bacteria, fungi, protozoans, microscopic algae, and also viruses.

"Mimetic" refers to a molecule that closely resembles a second molecule and has a similar effect or function as that of the second molecule.

"Moiety" refers to one of the component parts of a molecule. While there are normally two moieties in a single molecule, there may be more than two moieties in a single molecule.

"Molecular pattern" refers to a chemical structure or motif that is typically a component of microorganisms, or certain other organisms, but which is not typically produced by normal human cells or by other normal animal cells. Molecular patterns are found in, or composed of, the following types of molecules: lipopolysaccharides, peptidoglycans, lipoteichoic acids, phosphatidyl cholines, lipoproteins, bacterial DNAs, viral single and double-stranded RNAs, certain viral glycoproteins, unmethylated CpG-DNAs, mannans, and a variety of other bacterial, fungal and yeast cell wall components and the like.

"Non-protein chimeric construct" or "non-protein chimera" refers to a "chimeric construct" wherein either the antigen or the PAMP or the PAMP mimetic, or two or more of them, is not an amino acid polymer.

"Pathogen-Associated Molecular Pattern" or "PAMP" refers to a molecular pattern found in a microorganism but not in humans, which, when it binds a PRR, can trigger an innate immune response. Thus, as used herein, the term "PAMP" includes any such microbial molecular pattern and is not limited to those associated with pathogenic microorganisms or microbes. As used herein, the term "PAMP" includes a PAMP, derivative or portion of a PAMP that is immunostimulatory, and any immunostimulatory molecule derived from any PAMP. These structures, or derivatives thereof, are potential initiators of innate immune responses, and therefore, ligands for PRRs, including Toll receptors and TLRs. "PAMPs" are

immunostimulatory structures that are found in, or composed of molecules including, but not limited to, lipopolysaccharides; phosphatidyl choline; glycans, including peptidoglycans; teichoic acids, including lipoteichoic acids; proteins, including lipoproteins and lipopeptides; outer membrane proteins (OMPs), outer surface proteins (OSPs) and other protein components of the bacterial cell walls and Flagellins; bacterial DNAs; single and double-stranded viral RNAs; unmethylated CpG-DNAs; mannans; mycobacterial membranes; porins; and a variety of other bacterial and fungal cell wall components, including those found in yeast. Additional examples of PAMPs are provided in the Detailed Description section included herein.

"PAMP/antigen conjugate" refers to an antigen and a PAMP or PAMP mimetic that are covalently or noncovalently linked. A conjugate may be comprised of a protein PAMP or antigen and a non-protein PAMP or antigen.

"PAMP/antigen fusion" or "PAMP/antigen chimera" refers to any protein fusion formed between a PAMP or PAMP mimetic and an antigen.

"Passive immunization" refers to the administration of antibodies or primed lymphocytes to an individual in order to confer immunity.

"PAMP mimetic" refers to a molecule that, although it does not occur in microorganisms, is analogous to a PAMP in that it can bind to a PRR and such binding can trigger an innate immune response. A PAMP mimetic can be a naturally-occurring molecule or a partially or totally synthetic molecule. As an example, and not by way of limitation, certain plant alkaloids, such as taxol, are PRR ligands, have an immunostimulatory effect on the innate immune system, and thus behave as PAMP mimetics. (Kawasaki *et al.* (2000) *J. Biol. Chem.* 275(4): 2251-2254).

"Pattern Recognition Receptor" or "PRR" refers to a member of a family of receptors of the innate immune system that, upon binding a PAMP, an immunostimulatory portion or derivative thereof, can initiate an innate immune response. Members of this receptor family are structurally different and belong to several different protein families. Some of these receptors recognize PAMPs directly (*e.g.*, CD14, DEC205, collectins), while others (*e.g.*, complement receptors) recognize the products generated by PAMP recognition. Members of these receptor families can, generally, be divided into three types: 1) humoral receptors circulating in the plasma; 2) endocytic receptors expressed on immune-cell surfaces, and 3) signaling receptors that can be expressed either on the cell surface or intracellularly. Cellular PRRs may be expressed on effector cells of the innate immune system, including cells that function as professional APCs in adaptive immunity, and also on cells such as surface epithelia that are the first to encounter pathogens during infection. PRRs may also induce the expression of a set of endogenous signals, such as inflammatory cytokines and chemokines. Examples of PRRs useful for the present invention include, but are not limited to, the following: C-type lectins (*e.g.*, humoral, such as collectins (MBL), and cellular, such as macrophage C-type lectins, macrophage mannose receptors, DEC205); proteins containing leucine-rich repeats (*e.g.*, Toll receptor and TLRs, CD14, RP105); scavenger receptors (*e.g.*, macrophage scavenger receptors, MARCO, WC1); and pentraxins (*e.g.*, C-reactive proteins, serum, amyloid P, LBP, BPIP, CD11b,C and CD18.

"Peptide mimetic" refers to a protein or peptide that closely resembles a non-protein molecule and has a similar effect or function to the non-protein molecule.

Alternatively, a peptide mimetic can be a non-protein molecule or non-peptide molecule that closely resembles a peptide or protein and has a similar effect or function to the peptide or protein.

"Pharmaceutically acceptable carrier" refers to a carrier that can be tolerated by a recipient animal, typically a mammal.

"Protein chimeric construct" refers to a chimeric construct wherein both the antigen and the PAMP or PAMP mimetic are amino acid polymers.

"Recombinant" refers to genetic material that is produced by splicing genes, gene derivatives or other genetic material. As used herein, "recombinant" also refers to the products produced from recombinant genes (*e.g.* recombinant protein).

"Spacer" refers to any chemical entity placed between two chemical moieties that serves to physically separate the latter two moieties. Thus, a chemical entity placed between a PAMP or PAMP mimetic and an antigen is a spacer. Examples of spacers include, but are not limited to, nucleic acids (*e.g.* untranscribed DNA between two stretches of transcribed DNA), amino acids, carbohydrates (*e.g.*, monosaccharides, disaccharides, trisaccharides), and lipids.

"Strong immune response" refers to an immune response, induced by the chimeric construct, that has about the same intensity or greater than the response induced by an antigen mixed with Complete Freund's Adjuvant (CFA).

"Therapeutically effective amount" refers to an amount of an agent (*e.g.*, a vaccine) that can produce a measurable positive effect in a patient.

"Toll-like receptor" (TLR) refers to any of a family of receptor proteins that are homologous to the *Drosophila melanogaster* Toll protein. TLRs also refer to type

I transmembrane signaling receptor proteins that are characterized by an extracellular leucine-rich repeat domain and an intracellular domain homologous to that of the interleukin 1 receptor. The TLR family includes, but is not limited to, mouse TLR2 and TLR4 and their homologues, particularly in other species including humans. This invention also defines Toll receptor proteins and TLRs wherein the nucleic acids encoding such proteins have at least about 70% sequence identity, more preferably, at least about 80% sequence identity, even more preferably, at least about 85% sequence identity, yet more preferably at least about 90% sequence identity, and most preferably at least about 95% sequence identity to the nucleic acid sequence encoding the Toll protein and the TLR proteins TLR2, TLR4 and other members of the TLR family. In addition, this invention also contemplates Toll receptors and TLRs wherein the amino acid sequences of such Toll receptors and TLRs have at least about 70% sequence identity, more preferably, at least about 80% sequence identity, even more preferably, at least about 85% sequence identity, yet more preferably at least about 90% sequence identity, and most preferably at least about 95% sequence identity to the amino acid sequences of the Toll protein and the TLRs, TLR2, TLR4 and their homologues.

"Tumor" refers to a mass of proliferating cells lacking, to varying degrees, normal growth control. As used herein, "tumors" include, at one extreme, slowly proliferating "benign" tumors, to, at the other extreme, rapidly proliferating "malignant" tumors that aggressively invade neighboring tissues.

"Vaccine" refers to a composition comprising an antigen, and optionally other ancillary molecules, the purpose of which is to administer such compositions to a

subject to stimulate an immune response specifically against the antigen and preferably to engender immunological memory that leads to mounting of an immune response should the subject encounter that antigen at some future time. Examples of other ancillary molecules are adjuvants, which are non-specific immunostimulatory molecules, and other molecules that improve the pharmacokinetic and/or pharmacodynamic properties of the antigen. Conventionally, a vaccine usually consists of the organism that causes a disease (suitably attenuated or killed) or some part of the pathogenic organism as the antigen. Attenuated organisms, such as attenuated viruses or attenuated bacteria, are manipulated so that they lose some or all of their ability to grow in their natural host. There are now a range of biotechnological approaches used to producing vaccines. (*See, e.g.*, W. Bains (1998) Biotechnology From A to Z, Second Edition, Oxford University Press). The various methods include, but are not limited to, the following:

1) Viral vaccines consisting of genetically altered viruses. The viruses can be engineered so that they are harmless but can still replicate (albeit inefficiently, sometimes) in cultured animal cells. Another approach is to clone the gene for a protein from a pathogenic virus into another, harmless virus, so that that resulting, engineered virus has certain immunologic properties of the pathogenic virus but does not cause any disease. Examples of the latter method include, but are not limited to, altered vaccinia and adenoviruses used as rabies vaccines for distribution with meat bait, and a vaccinia virus engineered to produce haemagglutinin and fusion proteins of rindepest virus of cattle;

2) Enhanced bacterial vaccines consisting of bacteria genetically engineered to enhance their value as vaccines when the bacteria are dead *(e.g., E. coli* vaccine for pigs, bacterial vaccine for furunculosis in salmon). Recombinant DNA techniques can be used to delete pathogenesis-causing genes in the bacteria or to engineer the protective epitope from a pathogen into a safe bacterium;

3) Biopharmaceutical vaccines consist of proteins, or portions of proteins, that are the same as the proteins in a viral, fungal or bacterial coat or wall, which can be made by recombinant DNA methods;

4) Multiple antigen peptides (MAPs) are peptide vaccines that are chemically attached (usually on a polylysine backbone), enabling several vaccines to be delivered at the same time;

5) Polyprotein vaccines consist of a single protein made by genetic engineering so that the different peptides from the organisms of interest form part of a continuous polypeptide chain; and

6) Vaccines produced in transgenic plants that can be used as food to provide oral vaccines (*e.g.*, vaccine delivery by eating bananas).

3. Specific Embodiments

A. Fusion Proteins

The present invention is based in part on the unexpected discovery that vaccines comprising chimeric constructs of a PAMP and an antigen (*e.g.*, the fusion protein BLP/Eα) exhibit the essential immunological characteristics or properties expected of a conventional vaccine supplemented with an adjuvant.

In one aspect, the present invention is based on the finding that BLP/Eα induces activation of NF-κB and production of IL-6 in macrophages and dendritic cells, respectively, demonstrating that the vaccine is capable of activating the innate immune system. The activity of BLP/Eα is comparable to that of LPS, and is not due to endotoxin contamination, as demonstrated by the lack of inhibition by polymyxin B.

In another aspect, the present invention is based on the finding that the BLP/Eα fusion protein induces maturation of dendritic cells, as demonstrated by the induction of the cell surface expression of the co-stimulatory molecule, B7.2. Additionally, BLP/Eα is appropriately targeted to the antigen processing and presentation pathway, and a functional Eα peptide/MHC class-II complex is generated. This result is demonstrated by FACS analysis using an antibody specific for the Eα peptide complexed with MHC class-II.

Moreover, the present invention is based on the surprising discovery that a recombinant vaccine comprising a BLP/Ea chimeric construct activates antigen-specific T-cell responses *in vitro* by stimulating dendritic cell activation and generating a specific ligand (Eα/MHC-II) for the T-cell receptor. Furthermore, the results of immunization of mice with BLP/Eα and the resultant antigen-specific T-cell responses demonstrate that the recombinant vaccine activates antigen-specific T-cell responses *in vivo*. For comparison, mice were immunized with Eα peptide mixed with Complete Freund's Adjuvant (CFA). The recombinant vaccine of the present invention induced an immune response in the mice that is stronger than that produced by Eα peptide mixed with CFA.

The present invention is also based on the surprising discovery that immunization with the recombinant vaccines that comprise the chimeric constructs of the present invention induce a minimal inflammatory reaction when compared to that induced by an adjuvant. However, as noted above, in spite of a reduced inflammatory response, the vaccine unexpectedly induced a strong immune response. Thus, the vaccine approach described in the present invention minimizes an undesired side effect (*e.g.*, an excessive inflammatory reaction) yet induces a very potent and specific immune response. The present invention also provides fusion proteins comprising at least one antigen molecule or antigen domain and at least one PAMP or PAMP mimetic for use as vaccines. Preferably, the fusion protein has maximal immunogenicity and induces only a modest inflammatory response. Increasing the number of antigens or antigen epitopes, by using multiple antigen proteins and/or multiple domains of the same antigen protein or of different antigen proteins, and/or some combination of the foregoing, are contemplated in this invention. It is within the skill of the artisan to determine the optimal ratio of PAMP to antigen molecules to maximize immunogenicity and minimize or control the inflammatory response.

There are several advantages of using a fusion system for the production of recombinant polypeptides. First, heterologous proteins and peptides are often degraded by host proteases; this may be avoided, especially for small peptides, by using a gene fusion expression system. Second, general and efficient purification schemes are established for several fusion partners. The use of a fusion partner as an affinity handle allows rapid isolation of the recombinant peptide. Third, by using different fusion partners, the recombinant product may be localized to different

compartments or it might be secreted; such strategy could lead to facilitation of purification of the fusion partner and/or directed compartmentalization of the fusion protein.

Additionally, various methods are available for chemical or enzymatic cleavage of the fusion protein that provides efficient strategies to obtain the desired cleavage product in large quantities. Frequently employed fusion systems are the Staphylococcal protein A fusion system and the synthetic ZZ variant which have IgG affinity and have been used for the generation of antibodies against short peptides; the glutathione S-transferase fusion system (Smith *et al.* (1988) *Gene* 60); the β-galactosidase fusion system; and the trpE fusion system (Yansura (1990) *Methods Enzym.* 185: 61). Some of these systems are commercially available as kits, including vectors, purification components and detailed instructions.

The present invention also contemplates modified fusion proteins having affinity for metal (metal ion) affinity matrices, whereby one or more specific metal-binding or metal-chelating amino acid residues are introduced, by addition, deletion, or substitution, into the fusion protein sequence as a tag. Optimally, the fusion partner, *e.g.*, the antigen or PAMP sequence, is modified to contain the metal-chelating amino acid tag; however the antigen or PAMP could also be altered to provide a metal-binding site if such modifications could be achieved without adversely effecting a ligand-binding site, an active site, or other functional sites, and/or destroying important tertiary structural relationships in the protein. These metal-binding or metal-chelating residues may be identical or different, and can be selected from the group consisting of cysteine, histidine, aspartate, tyrosine,

tryptophan, lysine, and glutamate, and are located so to permit binding or chelation of the expressed fusion protein to a metal. Histidine is the preferred metal-binding residue. The metal-binding/chelating residues are situated with reference to the overall tertiary structure of the fusion protein to maximize binding/chelation to the metal and to minimize interference with the expression of the fusion protein or with the protein's biological activity.

A fusion sequence of an antigen, PAMP and a tag may optionally contain a linker peptide. The linker peptide might separate a tag from the antigen sequence or the PAMP sequence. If the linker peptide so used encodes a sequence that is selectively cleavable or digestible by conventional chemical or enzymatic methods, then the tag can be separated from the rest of the fusion protein after purification. For example, the selected cleavage site within the tag may be an enzymatic cleavage site. Examples of suitable enzymatic cleavage sites include sites for cleavage by a proteolytic enzyme, such as enterokinase, Factor Xa, trypsin, collagenase, and thrombin. Alternatively, the cleavage site in the linker may be a site capable of cleavage upon exposure to a selected chemical (*e.g.*, cyanogen bromide, hydroxylamine, or low pH).

Cleavage at the selected cleavage site enables separation of the tag from the antigen/PAMP fusion protein. The antigen/PAMP fusion protein may then be obtained in purified form, free from any peptide fragment to which it was previously linked for ease of expression or purification. The cleavage site, if inserted into a linker useful in the fusion sequences of this invention, does not limit this invention.

Any desired cleavage site, of which many are known in the art, may be used for this purpose.

The optional linker peptide in a fusion protein of the present invention might serve a purpose other than the provision of a cleavage site. As an example, and not by limitation, the linker peptide might be inserted between the PAMP and the antigen to prevent or alleviate steric hindrance between the two domains. In addition, the linker sequence might provide for post-translational modification including, but not limited to, *e.g.*, phosphorylation sites, biotinylation sites, sulfation sites, carboxylation sites, lipidation sites, glycosylation sites and the like.

In one embodiment, the fusion protein of this invention contains an antigen sequence fused directly at its amino or carboxyl terminal end to the sequence of a PAMP. In another embodiment, the fusion protein of this invention, comprising an antigen and a PAMP sequence, is fused directly at its amino or carboxyl terminal end to the sequence of a tag. The resulting fusion protein is a soluble cytoplasmic fusion protein. In another embodiment, the fusion sequence further comprises a linker sequence interposed between the antigen sequence and a PAMP sequence or sequence of a tag. This fusion protein is also produced as a soluble cytoplasmic protein.

B. Antigens

As used herein, an "antigen" is any substance that induces a state of sensitivity and/or immune responsiveness after any latent period (normally, days to weeks in humans) and that reacts in a demonstrable way with antibodies and/or immune cells of the sensitized subject *in vivo* or *in vitro*. Examples of antigens include, but are not limited to, (1) microbial-related antigens, especially antigens of pathogens such as

viruses, fungi or bacteria, or immunogenic molecules derived from them; (2) "self" antigens, collectively comprising cellular antigens including cells containing normal transplantation antigens and/or tumor-related antigens, RR-Rh antigens and antigens characteristic of, or specific to particular cells or tissues or body fluids; (3) allergen-related antigens such as those associated with environmental allergens (*e.g.*, grasses, pollens, molds, dust, insects and dander), occupational allergens (*e.g.*, latex, dander, urethanes, epoxy resins), food (*e.g.*, shellfish, peanuts, eggs, milk products), drugs (*e.g.*, antibiotics, anesthetics) and (4) vaccines (e.g., flu vaccine).

Antigen processing and recognition of displayed peptides by T-lymphocytes depends in large part on the amino acid sequence of the antigen rather than the three-dimensional structure of the antigen. Thus, the antigen portion used in the vaccines of the present invention can contain epitopes or specific domains of interest rather than the entire sequence. In fact, the antigenic portions of the vaccines of the present invention can comprise one or more immunogenic portions or derivatives of the antigen rather than the entire antigen. Additionally, the vaccine of the present invention can contain an entire antigen with intact three-dimensional structure or a portion of the antigen that maintains a three-dimensional structure of an antigenic determinant, in order to produce an antibody response by B-lymphocytes against a spatial epitope of the antigen.

1. Pathogen-Related Antigens. Specific examples of pathogen-related antigens include, but are not limited to, antigens selected from the group consisting of vaccinia, avipox virus, turkey influenza virus, bovine leukemia virus, feline leukemia virus, avian influenza, chicken pneumovirosis virus, canine parvovirus, equine

influenza, FHV, Newcastle Disease Virus (NDV), Chicken/Pennsylvania/1/83 influenza virus, infectious bronchitis virus; Dengue virus, measles virus, Rubella virus, pseudorabies, Epstein-Barr Virus, HIV, SIV, EHV, BHV, HCMV, Hantaan, *C. tetani*, mumps, Morbillivirus, Herpes Simplex Virus type 1, Herpes Simplex Virus type 2, Human cytomegalovirus, Hepatitis A Virus, Hepatitis B Virus, Hepatitis C Virus, Hepatitis E Virus, Respiratory Syncytial Virus, Human Papilloma Virus, Influenza Virus, *Salmonella*, *Neisseria*, *Borrelia*, *Chlamydia*, *Bordetella*, and *Plasmodium and Toxoplasma*, *Cryptococcus*, *Streptococcus*, *Staphylococcus*, *Haemophilus*, *Diptheria*, *Tetanus*, *Pertussis*, *Escherichia*, *Candida*, *Aspergillus*, *Entamoeba*, *Giardia*, and *Trypanasoma*.

2. Cancer-Related Antigens. The methods and compositions of the present invention can also be used to produce vaccines directed against tumor-associated protein antigens such as melanoma-associated antigens, mammary cancer-associated antigens, colorectal cancer-associated antigens, prostate cancer-associated antigens and the like.

Specific examples of tumor-related or tissue-specific protein antigens useful in such vaccines include, but are not limited to, antigens selected from the group in the following table.

Cancer type	Antigens
Prostate	prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1
Melanoma	TRP-2, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside
Breast	Her2-neu, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF -1 anti-apoptotic factor, HOM-Mel-40/SSX2

Testis	MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1
Colorectal	EGFR, CEA
Lung	MAGE D, EGFR
Ovarian	Her-2neu
Several cancers	NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53 (especially mutated versions), EGFR
Miscellaneous tumor antigens	CDC27 (including the mutated form of the protein), triosephosphate isomerase

In order for tumors to give rise to proliferating and malignant cells, they must become vascularized. Strategies that prevent tumor vascularization have the potential for being therapeutic. The methods and compositions of the present invention can also be used to produce vaccines directed against tumor vascularization. Examples of target antigens for such vaccines are vascular endothelial growth factors, vascular endothelial growth factor receptors, fibroblast growth factors and fibroblast growth factor receptors and the like.

3. Allergen-Related Antigens. The methods and compositions of the present invention can be used to prevent or treat allergies and asthma. According to the present invention, one or more protein allergens can be linked to one or more PAMPs, producing a PAMP/allergen chimeric construct, and administered to subjects that are allergic to that antigen. Thus, the methods and compositions of the present invention can also be used to construct vaccines that may suppress allergic reactions. In this case, the allergen is associated with or combined with a PAMP, including but not limited to BLP or Flagellin, that can initiate a Th1 response upon binding to a TLR. Initiation of innate immunity via a TLR, for example, tends to be characterized by production and secretion of cytokines, such as IL-12, that elicit a so-called Th1 response in a subject, rather than the typical Th2 response that triggers B-cells to

produce immunoglobulin E, the initiator of typical allergic and/or hypersensitive responses. IL-12 produced by dendritic cells and macrophages upon PAMP binding to their TLRs will direct T-cell differentiation into Th1 effector cells. Cytokines produced by Th1 cells, such as Interferon-gamma, will block the differentiation of IL-4 producing Th2 cells and would thus prevent production of antibodies of the IgE isotype, which are responsible for allergic responses.

Specific examples of allergen-related protein antigens useful in the methods and compositions of the present invention include, but are not limited to: allergens derived from pollen, such as those derived from trees such as Japanese cedar (*Cryptomeria*, *Cryptomeria japonica*), grasses (*Gramineae*), such as orchard-grass (*Dactylis*, *Dactylis glomerata*), weeds such as ragweed (*Ambrosia*, *Ambrosia artemisiifolia*); specific examples of pollen allergens including the Japanese cedar pollen allergens Cry j 1 (*J. Allergy Clin. Immunol.* (1983)71: 77-86) and Cry j 2 (*FEBS Letters* (1988) 239: 329-332), and the ragweed allergens Amb a I.1, Amba I.2, Amb a I.3, Amb a I.4, Amb a II etc.; allergens derived from fungi (*Aspergillus*, *Candida*, *Alternaria*, etc.); allergens derived from mites (allergens from *Dermatophagoides pteronyssinus*, *Dermatophagoides farinae* etc.; specific examples of mite allergens including Der p I, Der p II, Der p III, Der p VII, Der f I, Der f II, Der f III, Der f VII *etc.*); house dust; allergens derived from animal skin debris, feces and hair (for example, the feline allergen Fel d I); allergens derived from insects (such as scaly hair or scale of moths, butterflies, *Chironomidae* etc., poisons of the *Vespidae*, such *as Vespa mandarinia*); food allergens (eggs, milk, meat, seafood, beans, cereals, fruits, nuts and vegetables *etc.*); allergens derived from parasites (such as roundworm

and nematodes, for example, *Anisakis*); and protein or peptide based drugs (such as insulin). Many of these allergens are commercially available.

In another embodiment, prophylactic treatment of chronic allergies can be accomplished by the administration of a protein PAMP. In a preferred embodiment, the PAMP of the prophylactic vaccine is an OMP, more preferably OspA, and most preferably BLP. Alternatively, Flagellin can be used as the PAMP.

4. Other Disease Antigens. Also contemplated in this invention are vaccines directed against antigens that are associated with diseases other than cancer, allergy and asthma. As one example of many, and not by limitation, an extracellular accumulation of a protein cleavage product of β-amyloid precursor protein, called "amyloid-β peptide", is associated with the pathogenesis of Alzheimer's disease. (Janus *et al.*, *Nature* (2000) 408: 979-982; Morgan *et al.*, *Nature* (2000) 408: 982-985). Thus, the chimeric construct used in the vaccines of the present invention can include amyloid-β peptide, or antigenic domains of amyloid-β peptide, as the antigenic portion of the construct, and a PAMP or PAMP mimetic. Examples of other diseases in which vaccines might be generated against self proteins or self peptides are shown in the following table.

Disease	**Antigens**
Autoimmune diseases	disease-linked HLA-alleles (e.g., HLA-DRB1, HLA-DR1, HLA-DR6 B1 proteins or fragments thereof, chain genes); TCR chain sub-groups; CD11a (leukocyte function-associated antigen 1; LFA-1); IFNγ; IL-10;TCR analogs; IgR analogs; 21-hydoxylase (for Addison's disease); calcium sensing receptor (for acquired

	hypoparathyroidism); tyrosinase (for vitiligo)
Cardiovascular disease	LDL receptor
Diabetes	glutamic acid decarboxylase (GAD);insulin B chain; PC-1; IA-2, IA-2b; GLIMA-38
Epilepsy	NMDA

C. PAMPs

PAMPs are discrete molecular structures that are shared by a large group of microorganisms. They are conserved products of microbial metabolism, which are not subject to antigenic variability and are distinct from self-antigens. (Medzhitov *et al.* (1997) *Current Opinion in Immunology* 9: 4).

PAMPs can be composed of or found in, but are not limited to, the following types of molecules: Flagellins, lipopolysaccharides (LPS), porins, lipid A-associated proteins (LAP), lipopolysaccharides, fimbrial proteins, unmethylated CpG motifs, bacterial DNAs, double-stranded viral RNAs, mannans, cell wall-associated proteins, heat shock proteins, glycoproteins, lipids, cell surface polysaccharides, glycans (*e.g.*, peptidoglycans), phosphatidyl cholines, teichoic acids (*e.g.*, lipoteichoic acids), mycobacterial cell wall components/membranes, bacterial lipoproteins (BLP), outer membrane proteins (OMP), and outer surface protein A (Osp A). (Henderson *et al.* (1996) *Microbiol. Review* 60: 316; Medzhitov *et al.* (1997) *Current Opinion in Immunology* 9: 4-9).

The preferred PAMPs of the present invention include those that contain a DNA-encoded protein component, such as BLP, *Neisseria* porin, OMP, Flagellin and OspA, as these can be used as fusion partners to prepare the preferred embodiment of

the invention, i.e., fusion proteins comprising a PAMP and an antigen, preferably a self-antigen. One preferable PAMP for use in the present invention is BLP because BLP is known to induce activation of the innate immune response (Henderson *et al.* (1996) *Microbiol. Review* 60: 316) and has been shown to be recognized by TLRs (Aliprantis *et al.* (1999) *Science* 285: 763). Flagellin has similarly been demonstrated to induce features of innate immunity (Eaves-Pyles *et al.*, (2001) *J. Immunol.* 166:1248; Gewirtz *et al.*, (2001) *J Clin Invest.* 107: 99); Aderem, *Presentation at Keystone Symposium, Keystone, CO, 2001*).

Additionally, the present invention contemplates derivatives, portions, parts, or peptides of PAMPs that are recognized by the innate immune system for generating vaccines. As used herein, the terms "fragments of PAMPs", "portions of PAMPs", "parts of PAMPs" and "peptides of PAMPs", all refer to an immunostimulatory part of an entire PAMP molecule. Thus, the PAMPs used in the vaccines of the present invention can comprise an immunostimulatory portion or derivative of the PAMP rather than the entire PAMP, for example E. Coli murein lipoprotein amino acids 1 to 24.

In another embodiment, the present invention contemplates peptide mimetics of non-protein PAMPs. Peptide mimetics of polysaccharides and peptidoglycans are examples of peptide mimetics which can be used in the present invention. The present invention contemplates using phage selection methods to identify peptide mimetics of these non-protein PAMPs. For example, an antibody raised against a non-protein PAMP can be used to screen a phage library containing randomized short-peptide sequences. Selected sequences are isolated and assayed to determine

their usefulness as a protein derivative of a non-protein PAMP in the chimeric constructs of the present invention. Such peptide mimetics are useful to produce the recombinant vaccines disclosed herein.

In yet another embodiment, the present invention contemplates further examples of PAMP mimics or PAMP mimetics in which analogs of amino acids and/or peptides are substituted for the amino acid and/or peptide residues, respectively, of a peptide-containing PAMP or a protein PAMP.

In another embodiment, the chimeric construct is a construct comprising CpG or CpG-DNA, and an antigen. The CpG or CpG-DNA can be conjugated to a protein or non-protein antigen. In addition, peptide mimetics of CpG or CpG-DNA, that mimic the structural, functional, antigenic or immunogenic properties of CpG, can be produced and used to generate an antigen-PAMP (where PAMP is a CpG peptide mimetic) protein chimeric construct. This chimeric construct can be produced by recombinant DNA techniques and the expressed fusion protein can be used in the compositions and methods of the present invention.

D. Peptide Mimetics

This invention also includes a mimetic of the three-dimensional structure of a PAMP or antigen. In particular, this invention also includes peptides that closely resemble the three-dimensional structure of non-peptide PAMPs and antigens. Such peptides provide alternatives to non-polypeptide PAMPs or antigens, respectively, by providing the advantages of, for example: more economical production, greater chemical stability, enhanced pharmacological properties (half-life, absorption,

potency, efficacy, and/or altered specificity (*e.g.*, a broad-spectrum of biological activities), and other advantages.

Conversely, analogs of PAMP and/or antigen proteins can be synthesized such that one or both consists partially or entirely of amino acid and /or peptide analogs. Such analogs can contain non-naturally-occurring amino acids, or naturally-occurring amino acids that do not commonly occur in proteins, including but not limited to, D-amino acids or amino acids such as β-alanine, ornithine or canavanine, and the like, many of which are known in the art. Alternatively, analogs of PAMPs and/or antigens can be synthesized such that one or both consists partially or entirely of peptide analogs containing non-peptide bonds, many examples of which are known in the art. Such analogs may provide greater chemical stability, enhanced pharmacological properties (half-life, absorption, potency, efficacy, etc.) and/or altered specificity (*e.g.*, a broad-spectrum of biological activities) when compared with the naturally-occurring PAMP and/or antigen as well as other advantages.

In one form, the contemplated molecular structures are peptide-containing molecules that mimic elements of protein secondary structure. (see, for example, Johnson *et al.* (1993) Peptide Turn Mimetics, in Biotechnology and Pharmacy, Pezzuto *et al.*, (editors) Chapman and Hall). Such molecules are expected to permit molecular interactions similar to the natural molecule.

In another form, analogs of peptides are commonly used in the pharmaceutical industry as non-peptide drugs with properties analogous to those of a subject peptide. These types of non-peptide compounds are also referred to as "peptide mimetics" or "peptidomimetics" (Fauchere (1986) *Adv. Drug Res.*15, 29-69; Veber *et al.* (1985)

Trends Neurosci. 8: 392-396; Evans *et al.* (1987) *J. Med. Chem.* 30: 1229-1239) and are usually developed with the aid of computerized molecular modeling.

Peptide mimetics that are structurally similar to therapeutically useful peptides may be used to produce an equivalent therapeutic or prophylactic effect. Generally, peptide mimetics are structurally similar to a paradigm polypeptide (*e.g.*, a polypeptide that has a biochemical property or pharmacological activity), but have one or more peptide linkages optionally replaced by a linkage selected from the group consisting of: -CH_2NH-, -CH_2S-, -CH_2-CH_2-, -CH=CH- (cis and trans), -$COCH_2$-, -$CH(OH)CH_2$-, -CH_2SO- and the like. (Morley (1980) *Trends Pharmacol. Sci.* 1: 463-468 (general review); Hudson *et al.* (1979) *Int. J. Pept. Protein Res.* 14: 177-185 (-CH_2NH-, CH_2CH_2-); Spatola *et al.* (1986) *Life Sci.* 38: 1243-1249 (-CH_2-S); Hann (1982) *J. Chem. Soc. Perkin Trans.* 1: 307-314 (-CH-CH-, *cis* and *trans*); Almquist *et al.* (1980) *J. Med. Chem.* 23: 1392-1398 (-$COCH_2$-); Jennings-White *et al.* (1982) *Tetrahedron Lett.* 23: 2533 (-$COCH_2$-); Holladay *et al.* (1983) *Tetrahedron Lett.* 24: 4401-4404 (-$C(OH)CH_2$-); and Hruby (1982) *Life Sci.* 31: 189-199 (-CH_2S-); each of which is incorporated herein by reference.).

Labeling of peptide mimetics usually involves covalent attachment of one or more labels, directly or through a spacer (*e.g.*, an amide group), to non-interfering position(s) on the peptide mimetic that are predicted by quantitative structure-activity data and molecular modeling. Such non-interfering positions generally are positions that do not form direct contacts with the macromolecule(s) (*e.g.*, in the present example they are not contact points in PAMP-PRR complexes) to which the peptide mimetic binds to produce the therapeutic effect. Derivitization (*e.g.*, labeling) of

peptide mimetics should not substantially interfere with the desired biological or pharmacological activity of the peptide mimetic.

PAMP peptide mimetics can be constructed by structure-based drug design through replacement of amino acids by organic moieties. (Hughes (1980) *Philos. Trans. R. Soc. Lond.* 290: 387-394; Hodgson (1991) *Biotechnol.* 9: 19-21; Suckling (1991) *Sci. Prog.* 75: 323-359).

The design of peptide mimetics can be aided by identifying amino acid mutations that increase or decrease binding of PAMP to its PRR. Approaches that can be used include the yeast two-hybrid method (Chien *et al.* (1991) *Proc. Natl. Acad. Sci. USA* 88: 9578-9582) and using the phage display method. The two-hybrid method detects protein-protein interactions in yeast. (Fields *et al.* (1989) *Nature* 340: 245-246). The phage display method detects the interaction between an immobilized protein and a protein that is expressed on the surface of phages such as lambda and M13. (Amberg *et al.* (1993) *Strategies* 6: 2-4; Hogrefe *et al.* (1993) *Gene* 128: 119-126). These methods allow positive and negative selection for protein-protein interactions and the identification of the sequences that determine these interactions.

Conventional methods of peptide synthesis are known in the art. (Jones (1992) Amino Acid and Peptide Synthesis, Oxford University Press; Jung (1997) Combinatorial Peptide and Nonpeptide Libraries: A Handbook, John Wiley; Bodanszky *et al.* (1993) Peptide Chemistry - A Practical Textbook, Springer Verlag).

E. Flagellin PAMPs

Bacterial flagella are made up of the structural protein Flagellin, which induces expression of chemokine IL-8 and activation of NF-κB in human and mouse

cells. Additionally Flagellin activates mammalian cells via a Toll-Like Receptor, TLR5. These findings, as well as the fact that Flagellin proteins are extremely conserved in bacteria, indicate that Flagellin is a pathogen-associated molecular pattern (PAMP) that would be recognized by the innate immune system.

Because Flagellin is a protein and a PAMP, it is also be suitable for the generation of recombinant fusion vaccines. As described in the Examples section below, a series of fusion constructs were tested for their ability to activate the mammalian innate immune system. Activation of NF-κB was used as a read-out in the experiments because it is a critical pathway indicative of the triggering of the Toll-Like Receptors, and has been demonstrated to be a property of the recombinant fusion vaccines.

F. Conservative Variants of PAMPs

The present invention also contemplates conservative variants of naturally-occurring protein PAMPs, peptides of PAMPs, and peptide mimetics of PAMPs that recognize the corresponding PRRs. Such variants are examples of PAMP mimetics. The conservative variations include mutations that substitute one amino acid for another within one of the following groups:

1. Small aliphatic, nonpolar or slightly polar residues: Ala, Ser, Thr, Pro and Gly;

2. Polar, negatively charged residues and their amides: Asp, Asn, Glu and Gln;

3. Polar, positively charged residues: His, Arg and Lys;

4. Large aliphatic, nonpolar residues: Met, Leu, Ile, Val and Cys; and

5. Aromatic residues: Phe, Tyr and Trp.

The types of substitutions selected may be based on the analysis of the frequencies of amino acid substitutions among the PAMPs of different species (Schulz *et al.* Principles of Protein Structure, Springer-Verlag, 1978, pp. 14-16) on the analyses of structure-forming potentials developed by Chou and Fasman (Chou *et al.* (1974) *Biochemistry* 13: 211; Schulz *et al.* (1978) Principles in Protein Structure, Springer-Verlag, pp. 108-130), and on the analysis of hydrophobicity patterns in proteins developed by Kyte and Doolittle (Kyte *et al.* (1982) *J. Mol. Biol.* 157: 105-132).

The present invention also contemplates conservative variants that do not affect the ability of the PAMP to bind to its PRR. The present invention includes PAMPs with altered overall charge, structure, hydrophobicity/hydrophilicity properties produced by amino acid substitution, insertion, or deletion that retain and/or improve the ability to bind to their receptor. Preferably, the mutated PAMP has at least about 70% sequence identity, more preferably at least about 80% sequence identity, even more preferably, at least about 85% sequence identity, yet more preferably at least about 90% sequence identity, and most preferably at least about 95% sequence identity to its corresponding wild-type PAMP.

Numerous methods for determining percent homology are known in the art. Version 6.0 of the GAP computer program is available from the University of Wisconsin Genetics Computer Group and utilizes the alignment method of Needleman and Wunsch, as revised by Smith and Waterman. (Needleman *et al.* (1970) *J. Mol. Biol.* 48: 443; Smith *et al.* (1981) *Adv. Appl. Math.* 2: 482). Numerous methods for determining percent identity are also known in the art, and a

preferred method is to use the FASTA computer program, which is also available from the University of Wisconsin Genetics Computer Group.

G. Combination Treatments

The present invention provides methods of treating subjects comprising passively immunizing an individual by administering antibodies or activated immune cells to a subject to confer immunity, and administering a vaccine comprising a fusion protein of the present invention, preferably wherein the administered antibody or activated immune cells are directed against the same antigen of the fusion protein of the vaccine. Such treatments can be sequential, in either order or simultaneous. This combination therapy contemplates the use of either monoclonal or polyclonal antibodies that are directed against the antigen of the PAMP/antigen fusion.

The present invention provides methods of treating subjects comprising passively immunizing an individual by administering antibodies or activated immune cells to a subject to confer immunity, and administering a vaccine comprising a chimeric construct of the present invention, wherein the administered antibody or activated immune cells are preferably directed against the same antigen of the chimeric construct. Such treatments can be sequential, in either order, or simultaneous. This combination therapy contemplates the use of either monoclonal or polyclonal antibodies that are directed against the antigen of the PAMP/antigen chimeric construct.

The present invention also contemplates the use of a vaccine comprising a chimeric construct of the present invention in combination with a second treatment where such second treatment is not an immune-directed therapy. A non-limiting

example of such combination therapy is the combination of a vaccine comprising a fusion protein of the present invention in combination with a chemotherapeutic agent, such as an anti-cancer chemotherapeutic agent. A further non-limiting example of such combination therapy is the combination of a vaccine comprising a fusion protein construct of the present invention in combination with an anti-angiogenic agent. A further non-limiting example of such combination therapy is the combination of a vaccine comprising a fusion protein of the present invention in combination with radiation therapy, such as an anti-cancer radiation therapy. Yet a further non-limiting example of combination therapy is the combination of a vaccine comprising a fusion protein of the present invention in combination with surgery, such as surgery to remove or reduce vascular blockage.

Also contemplated in this invention is a combination of more than one other therapeutic with a vaccine contemplated in this invention. A non-limiting example is a combination of a vaccine contemplated in this invention in combination with passive immunotherapy treatment and chemotherapy treatment.
In such combination treatments as can be contemplated herein, treatments can be sequential or simultaneous.

The PAMP domain can comprise the entire PAMP or an immunostimulatory portion of the PAMP. Preferably, the fusion protein has maximal immunogenicity and induces minimal inflammatory response. Such desirable properties might be achieved, for example, by using two or more different antigens, and/or portions of different antigens, and/or by using more than one copy of the same antigen or portions of the same antigen, and/or by a combination of both. Alternatively, two or more

different PAMPs, or portions of different PAMPs, and/or two or more copies of the same PAMP, or portions of the same PAMP, and/or a combination of both can be used. A further embodiment contemplates fusion proteins containing multiple antigens, and/or portions of antigens, together with multiple PAMPs, and/or portions of PAMPs. It is within the skill of the artisan to determine the desirable ratio of PAMP to antigen domains to maximize immunogenicity and minimize inflammatory response.

There are several advantages of using a fusion system for the production of recombinant polypeptides. First, heterologous proteins and peptides are often degraded by host proteases; this may be avoided, especially for small peptides, by using a gene fusion expression system. Second, general and efficient purification schemes are established for several fusion partners. The use of a fusion partner as an affinity handle allows rapid isolation and purification of the recombinant peptide. Third, by using different fusion partners, the recombinant product may be localized to different compartments or it might be secreted; such strategy could lead to facilitation of purification of the fusion partner and/or directed compartmentalization of the fusion protein.

Additionally, various methods are available for chemical or enzymatic cleavage of the fusion protein that provides efficient strategies to obtain the desired peptide in large quantities. Frequently employed fusion systems include: the *Staphylococcal* protein A fusion system and the synthetic ZZ variant, both of which have IgG affinity and have been used for the generation of antibodies against short peptides; the glutathione S-transferase fusion system (Smith *et al.* (1988) *Gene* 60);

the β-galactosidase fusion system; and the trpE fusion system (Yansura (1990) *Methods Enzym.* 185: 61). Some of these systems are commercially available as kits, including vectors, purification components and detailed instructions.

The present invention also contemplates modified fusion proteins having affinity for metal ion affinity matrices, whereby one or more specific metal-binding or metal-chelating amino acid residues are introduced, by addition, deletion, or substitution, into the fusion protein sequence as a tag. Optimally, a fusion partner, either an antigen or a PAMP domain, is modified to contain an added metal-chelating amino acid tag. The sequence of an antigen or PAMP domain, however, could also be altered to provide a metal-binding site if such modifications could be achieved without adversely affecting a ligand-binding site, an active site, or other functional sites, and/or destroying important tertiary structural relationships in the protein. These metal-binding or metal-chelating residues may be identical or different, and can be selected from the group consisting of cysteine, histidine, aspartate, tyrosine, tryptophan, lysine, and glutamate, and are located so to permit binding or chelation of the expressed fusion protein to a metal. Histidine is the preferred metal-binding residue. The metal-binding/chelating residues are situated with reference to the overall tertiary structure of the fusion protein to maximize binding/chelation to the metal and to minimize interference with the expression of the fusion protein its biological activity.

A fusion sequence of an antigen, PAMP and a tag, may optionally contain a linker peptide. The linker peptide might separate a tag from the antigen sequence or the PAMP sequence. If the linker peptide so used encodes a sequence that is

selectively cleavable or digestible by conventional chemical or enzymatic methods, then the tag can be separated from the rest of the fusion protein after purification. For example, the selected cleavage site within the tag may be an enzymatic cleavage site. Examples of suitable enzymatic cleavage sites include sites for cleavage by a proteolytic enzyme, such as enterokinase, Factor Xa, trypsin, collagenase, thrombin and the like. Alternatively, the cleavage site in the linker may be a site capable of cleavage upon exposure to a selected chemical or condition, *e.g.*, cyanogen bromide, hydroxylamine, or low pH, or other chemicals or conditions known in the art.

Cleavage at the selected cleavage site enables separation of the tag from the antigen/PAMP fusion protein. The antigen/PAMP fusion protein may then be obtained in purified form, free from any peptide derivative to which it was previously linked for ease of expression or purification. The cleavage site, if inserted into a linker useful in the fusion sequences of this invention, does not limit this invention. Any desired cleavage site, of which many are known in the art, may be used for this purpose.

Another use of linker peptides might be to direct cleavage of the antigen in intracellular processing so as to facilitate peptide presentation on the surface of the APC. Appropriate cleavage sites might be inserted via linkers such that the fusion protein is not cleaved until it is internalized by the APC. Under such circumstances, such a peptide cleavage site can be introduced via a linker between the PAMP and the antigen to generate intracellular antigen free of PAMP. Such directed cleavage could also be used particularly to facilitate production within the APC of specific peptides that have been identified as interacting with particular HLA haplotypes.

Alternatively, different domains from a single antigen or from more than one antigen might be separated by linkers containing cleavage sites so that these epitopes could be appropriately processed for presentation on the surface of the APC.

The optional linker peptide in a fusion protein of the present invention might serve a purpose other than the provision of a cleavage site. As an example, and not by limitation, the linker peptide might be inserted between a PAMP domain and an antigen domain to prevent or alleviate steric hindrance between the two domains. In addition, the linker sequence might provide for post-translational modification including, but not limited to, *e.g.*, phosphorylation sites, biotinylation sites, sulfation sites, carboxylation sites, glycosylation sites, lipidation sites, and the like.

In one embodiment, the fusion protein of this invention contains a domain of an antigen or an immunogenic portion of an antigen fused directly at its amino or carboxyl terminal end to the domain of a PAMP or an immunostimulatory portion of a PAMP. In another embodiment, the fusion protein of this invention contains a domain of a PAMP, or an immunostimulatory portion of a PAMP, or a sequence that can be post-translationally modified to produce a PAMP, inserted within the domain of an antigen, or an immunogenic portion of an antigen. In yet another embodiment, the fusion protein of this invention contains a domain of an antigen, or an immunogenic portion of an antigen, inserted within the domain of a PAMP, or an immunostimulatory portion of a PAMP, or a sequence that can be post-translationally modified to produce a PAMP. In another embodiment, the fusion protein of this invention, comprising an antigen and a PAMP sequence, is fused directly at its amino or carboxyl terminal end to the sequence of a tag. The resulting fusion protein is a

soluble cytoplasmic fusion protein. In another embodiment, the fusion sequence further comprises a linker sequence interposed between the antigen sequence and a PAMP sequence or sequence of a tag. This fusion protein is also produced as a soluble cytoplasmic protein.

H. Recombinant Technology

Protein PAMPs, protein antigens, and derivatives thereof can be generated using standard peptide synthesis technology. Alternatively, recombinant methods can be used to generate nucleic acid molecules that encode protein PAMPs, protein antigens and derivatives thereof.

Nucleic acids encoding PAMP/antigen fusions (*e.g.*, synthetic oligo- and polynucleotides) can easily be synthesized by chemical techniques, for example, the phosphotriester method of Matteucci, *et al.* ((1981) *J. Am. Chem. Soc.* 103: 3185-3191) or using automated synthesis methods. In addition, larger nucleic acids can readily be prepared by well known methods, such as synthesis of a group of oligonucleotides that define various modular segments of the nucleic acid encoding the PAMP/antigen fusion, followed by ligation of oligonucleotides to build the complete nucleic acid molecule.

The present invention further provides recombinant nucleic acid molecules that encode PAMP/antigen fusion proteins. As used herein, a "recombinant nucleic acid molecule" refers to a nucleic acid molecule that has been subjected to molecular manipulation *in vitro*. Methods for generating recombinant nucleic acid molecules are well known in the art. (Sambrook *et al.* (1989) Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Press). In the preferred recombinant nucleic acid

molecules, a nucleotide sequence that encodes a PAMP/antigen fusion is operably linked to one or more expression control sequences and/or vector sequences.

The choice of vector and/or expression control sequences to which one of the PAMP/antigen fusion encoding sequences of the present invention is operably linked depends directly, as is well known in the art, on the functional properties desired (*e.g.*, protein expression), and the host cell to be transformed. A vector contemplated by the present invention is at least capable of directing the replication or insertion into the host chromosome, and preferably also expression, of a nucleotide sequence encoding a PAMP/antigen fusion.

Expression control elements that are used for regulating the expression of an operably linked protein encoding sequence are known in the art and include, but are not limited to, inducible promoters, constitutive promoters, secretion signals, enhancers, transcription terminators and other regulatory elements. Preferably, an inducible promoter that is readily controlled, such as being responsive to a nutrient in the medium, is used.

In one embodiment, the vector containing a nucleic acid molecule encoding a PAMP/antigen fusion will include a prokaryotic replicon, *e.g.*, a nucleotide sequence having the ability to direct autonomous replication and maintenance of the recombinant nucleic acid molecule intrachromosomally in a prokaryotic host cell, such as a bacterial host cell, transformed therewith. Such replicons are well known in the art. In addition, vectors that include a prokaryotic replicon may also include a gene whose expression confers a detectable marker such as a drug resistance. Typical

bacterial drug resistance genes are those that confer resistance to ampicillin (Amp) or tetracycline (Tet).

Vectors that include a prokaryotic replicon can further include a prokaryotic or viral promoter capable of directing the expression (transcription and translation) of the PAMP/antigen fusion in a bacterial host cell, such as *E. coli*. A promoter is an expression control element formed by a nucleic acid sequence that permits binding of RNA polymerase and transcription to occur. Promoter sequences compatible with bacterial hosts are typically provided in plasmid vectors containing convenient restriction sites for insertion of a nucleic acid segment of the present invention. Typical of such vector plasmids are pUC8, pUC9, pBR322 and pBR329 available from Biorad Laboratories (Richmond, CA), pPL and pKK223 available from Amersham Pharmacia Biotech, Piscataway, NJ.

Expression vectors compatible with eukaryotic cells, preferably those compatible with vertebrate cells, can also be used to express nucleic acid molecules that contain a nucleotide sequence that encodes a PAMP/antigen fusion. Eukaryotic cell expression vectors are well known in the art and are available from several commercial sources. Typically, such vectors provide convenient restriction sites for insertion of the desired DNA segment. Typical of such vectors are pSVL and pKSV-10 (Amersham Pharmacia Biotech), pBPV-1/pML2d (International Biotechnologies, Inc.), pTDT1 (ATCC, #31255), the vector pCDM8 described herein, and other like eukaryotic expression vectors.

Eukaryotic cell expression vectors used to construct the recombinant molecules of the present invention may further include a selectable marker that is

effective in a eukaryotic cell, preferably a drug resistance selection marker. A preferred drug resistance marker is the gene whose expression results in neomycin resistance, *e.g.*, the neomycin phosphotransferase (*neo*) gene. (Southern *et al. (1982) J. Mol. Anal. Genet.* 1:327-341). Alternatively, the selectable marker can be present on a separate plasmid, and the two vectors are introduced by cotransfection of the host cell, and selected by culturing in the presence of the appropriate drug for the selectable marker.

The present invention further provides host cells transformed with a nucleic acid molecule that encodes a PAMP/antigen fusion protein of the present invention. The host cell can be either prokaryotic or eukaryotic. Eukaryotic cells useful for expression of a PAMP/antigen fusion protein are not limited, so long as the cell line is compatible with cell culture methods and compatible with the propagation of the expression vector and expression of the fusion protein. Preferred eukaryotic host cells include, but are not limited to, yeast, insect and mammalian cells, preferably vertebrate cells such as those from a mouse, rat, monkey or human fibroblastic cell line.

Any prokaryotic host can be used to express a recombinant nucleic acid molecule. The preferred prokaryotic host is *E. coli*. In embodiments where the PAMP is a lipoprotein, expression of the PAMP/antigen fusion protein in a bacterial cell is preferred. Expression of the nucleic acid in a bacterial cell line is desirable to ensure proper post-translational modification of the protein portion of the lipoprotein. Preferably, the host cells selected for expression of the PAMP/antigen fusion (*e.g.*

lipoprotein/antigen fusion) is the cell that natively produces the lipoprotein of the lipoprotein/antigen fusion.

Transformation of appropriate cell hosts with nucleic acid molecules encoding a PAMP/antigen fusion of the present invention is accomplished by well known methods that typically depend on the type of vector and host system employed. With regard to transformation of prokaryotic host cells, electroporation and salt treatment methods are typically employed. (*See e.g.,* Cohen *et al.* (1972) *Pro.c Natl. Acad. Sci. USA* 69:2110; Maniatis *et al.*, Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY (1982); Sambrook *et al.* (1989)). With regard to transformation of vertebrate cells with vectors containing rDNAs, electroporation, cationic lipid or salt treatment methods are typically employed. (*See e.g.,* Graham *et al.*, *Virology* (1973) 52:456; Wigler *et al.* (1979) *Proc. Natl. Acad. Sci. U.S.A.* 76:1373-76).

Successfully transformed cells, *e.g.*, cells that contain a nucleic acid molecule encoding the PAMP/antigen fusions of the present invention, can be identified by well known techniques. For example, cells resulting from the introduction of a nucleic acid molecule encoding the PAMP/antigen fusions of the present invention can be cloned to produce single colonies. Cells from those colonies can be harvested, lysed and their nucleic acids content examined for the presence of the recombinant molecule using a method such as that described by Southern (1975) (*J. Mol. Biol.* 98: 503), or Berent *et al.* (1985) (*Biotech.* 3: 208) or the proteins produced from the cell assayed via an immunological method.

The present invention further provides methods for producing a PAMP/antigen fusion protein that uses one of the nucleic acid molecules herein described. In general terms, the production of a recombinant protein typically involves the following steps.

First, a nucleic acid molecule is obtained that encodes a PAMP/antigen fusion protein. Said nucleic acid molecule is then preferably placed in an operable linkage with suitable control sequences, as described above. The expression unit is used to transform a suitable host and the transformed host is cultured under conditions that allow the production of the PAMP/antigen fusion protein. Optionally, the fusion protein is isolated from the medium or from the cells; recovery and purification of the fusion protein may not be necessary in some instances where some impurities may be tolerated.

Each of the foregoing steps can be done in a variety of ways. For example, the desired coding sequences may be obtained from genomic fragments and used directly in an appropriate host. The construction of expression vectors that are operable in a variety of hosts is accomplished using an appropriate combination of replicons and control sequences. The control sequences, expression vectors, and transformation methods are dependent on the type of host cell used to express the gene and were discussed in detail earlier. A skilled artisan can readily adapt any host/expression system known in the art for use with the nucleotide sequences described herein to produce a PAMP/antigen fusion protein.

Endonucleases are nucleases that are able to break internal phosphodiester bonds within a nucleic acid molecule. Examples of nucleases include, but are not

limited to, S1 endonuclease from the fungus *Aspergillus oryzae*, deoxyribonuclease (DNase I), and restriction endonucleases. The cutting and joining processes that underlie DNA manipulation are carried out by enzymes called restriction endonucleases (for cutting) and ligases (for joining). Suitable restriction endonuclease cleavage sites can, if not normally available, be added to the ends of the coding sequence so as to provide an excisable nucleic acid sequence to insert into these vectors.

In addition, restriction endonuclease cleavage sites may also be inserted in the nucleic acid sequence encoding the PAMP/antigen fusion protein. Preferably, these cleavage sites are engineered between nucleotide sequences encoding identical or different PAMPs; between identical or different antigens, or between nucleotide sequences encoding PAMP and antigen. Appropriate cleavage sites well know to those skilled in the art include, but are not limited to, the following: *Eco*RI, *Bam*HI, *Bgl*II, *Pvu*I, *Pvu*II, *Hind*III, *Hinf*I, *Sau*3A, *Alu*I, *Taq*I, *Hae*III and *Not*I. (T.A. Brown (1996) Gene Cloning: An Introduction, Second Edition, Chapman & Hall, Chapter 4:49-83).

I. Conjugates

The present invention also includes "conjugates" which comprise two or more molecules that are covalently linked, or noncovalently linked but in association with each other. Thus, vaccines of the present invention include PAMP/antigen conjugates such as, but not limited to, the following: protein/nucleic acid conjugates, nucleic acid/protein conjugates, nucleic acid/nucleic acid conjugates, peptide-mimetic/nucleic acid conjugates, nucleic acid/peptide mimetic conjugates, peptide mimetic/peptide

mimetic conjugates, lipopolysaccharide/protein conjugates, lipoprotein/protein conjugates, RNA/protein conjugates, CpG-DNA/protein conjugates, nucleic acid analog/protein conjugates, and mannan/protein conjugates. To the extent that PAMPs identified in the future are comprised of yet other chemical classes, conjugates containing such chemicals in combination with antigen domains can also be contemplated.

Methods for the conjugation of polypeptides, carbohydrates, and lipids with DNA are well known to the artisan. *See e.g.,* U.S. Pat. Nos. 4,191,668, 4,650,625, 5,162,515, 5,700,922, 5,786,461, 6,06,0056; and J. *Clin. Invest.* (1988) 82:1901-1907.

Non-protein PAMPs such as CpG or CpG-DNA, and lipopolysaccharides may be conjugated to protein or non-protein antigens by conventional techniques. For example, PAMP/antigen conjugates may be linked through polymers such as PEG, poly-D-lysine, polyvinyl alcohol, polyvinylpyrollidone, immunoglobulins, and copolymers of D-lysine and D-glutamic acid. Conjugation of the PAMP and antigen to the polymer linker may be achieved in any number of ways, typically involving one or more crosslinking agents and functional groups on the PAMP and antigen. Polypeptide PAMPs and antigens will contain amino acid side chains such as amino, carbonyl, or sulfhydryl groups that will serve as sites for linking the PAMP and antigen to each other. Residues that have such functional groups may be added to either the PAMP or antigen. Such residues may be incorporated by solid phase synthesis techniques or recombinant techniques, both of which are well known in the peptide synthesis arts.

In the case of carbohydrate or lipid analogs, functional amino and sulfhydryl groups may be incorporated therein by conventional chemistry. For instance, primary amino groups may be incorporated by reaction with ethylenediamine in the presence of sodium cyanoborohydride and sulfhydryls may be introduced by reaction of cysteamine dihydrochloride followed by reduction with a standard disulfide reducing agent. In a similar fashion the polymer linker may also be derivatized to contain functional groups if it does not already possess appropriate functional groups. Heterobifunctional crosslinkers, such as sulfosuccinimidyl(4-iodoacetyl) aminobenzoate, which link the .epsilon. amino group on the D-lysine residues of copolymers of D-lysine and D-glutamate to a sulfhydryl side chain from an amino terminal cysteine residue on the peptide to be coupled, are also useful to increase the ratio PAMPs or antigens in the conjugate.

J. Vaccine Formulation and Delivery

The vaccines of the present invention contain one or more PAMPs, immunostimulatory portions, or immunostimulatory derivatives thereof (*e.g.*, a domain recognized by the innate immune system), and one or more antigens, immunogenic portions, or immunogenic derivatives thereof (*e.g.*, a domain recognized by the adaptive immune system). Since a PAMP mimetic, by definition, has the ability to bind PRRs and initiate an innate immune response, vaccine formulations contemplated by this invention include PAMP mimetics in place of PAMPs. Thus, the present invention contemplates vaccines comprising chimeric constructs including at least one antigen domain and at least one PAMP domain. In

one specific embodiment, the vaccines of the present invention comprise a BLP/Eα fusion protein.

The vaccines, comprising the chimeric constructs of the present invention, can be formulated according to known methods for preparing pharmaceutically useful compositions, whereby the chimeric constructs are combined in a mixture with a pharmaceutically acceptable carrier. A composition is said to be a "pharmaceutically acceptable carrier" if its administration can be tolerated by the recipient and if that composition renders the active ingredient(s) accessible at the site where the action is required. Sterile phosphate-buffered saline is one example of a pharmaceutically acceptable carrier. Other suitable carriers are well-known to those in the art. (Ansel *et al.*, Pharmaceutical Dosage Forms and Drug Delivery Systems, 5th Edition (Lea & Febiger 1990); Gennaro (ed.), Remington's Pharmaceutical Sciences 18th Edition (Mack Publishing Company 1990)).

Examples of several other excipients that can be contemplated may include, water, dextrose, glycerol, ethanol, and combinations thereof. The vaccines of the present invention may further contain auxiliary substances, such as wetting or emulsifying agents, pH buffering agents, stabilizers or other carriers that include, but are not limited to, agents such as aluminum hydroxide or phosphate (alum), commonly used as a 0.05 to 0.1 percent solution in phosphate buffered saline, to enhance the effectiveness thereof.

The chimeric constructs of the present invention can be used as vaccines by conjugating to soluble immunogenic carrier molecules. Suitable carrier molecules include protein, including keyhole limpet hemocyanin, which is a preferred carrier

protein. The chimeric construct can be conjugated to the carrier molecule using standard methods. (Hancock *et al.*, "Synthesis of Peptides for Use as Immunogens," in Methods in Molecular Biology: Immunochemical Protocols, Manson (ed.), pages 23-32 (Humana Press 1992)).

Furthermore, the present invention contemplates a vaccine composition comprising a pharmaceutically acceptable injectable vehicle. The vaccines of the present invention may be administered in conventional vehicles with or without other standard carriers, in the form of injectable solutions or suspensions. The added carriers might be selected from agents that elevate total immune response in the course of the immunization procedure.

Liposomes have been suggested as suitable carriers. The insoluble salts of aluminum, that is aluminum phosphate or aluminum hydroxide, have been utilized as carriers in routine clinical applications in humans. Polynucleotides and polyelectrolytes and water soluble carriers such as muramyl dipeptides have been used.

Preparation of injectable vaccines of the present invention, includes mixing the chimeric construct with muramyl dipeptides or other carriers. The resultant mixture may be emulsified in a mannide monooleate/squalene or squalane vehicle. Four parts by volume of squalene and/or squalane are used per part by volume of mannide monooleate. Methods of formulating vaccine compositions are well-known to those of ordinary skill in the art. (Rola, Immunizing Agents and Diagnostic Skin Antigens. In: Remington's Pharmaceutical Sciences,18th Edition, Gennaro (ed.), (Mack Publishing Company 1990) pages 1389-1404).

Additional pharmaceutical carriers may be employed to control the duration of action of a vaccine in a therapeutic application. Control release preparations can be prepared through the use of polymers to complex or adsorb chimeric construct. For example, biocompatible polymers include matrices of poly(ethylene-co-vinyl acetate) and matrices of a polyanhydride copolymer of a stearic acid dimer and sebacic acid. (Sherwood *et al.* (1992) *Bio/Technology* 10: 1446). The rate of release of the chimeric construct from such a matrix depends upon the molecular weight of the construct, the amount of the construct within the matrix, and the size of dispersed particles. (Saltzman *et al.* (1989) *Biophys. J.* 55: 163; Sherwood *et al., supra.*; Ansel *et al.* Pharmaceutical Dosage Forms and Drug Delivery Systems, 5th Edition (Lea & Febiger 1990); and Gennaro (ed.), Remington's Pharmaceutical Sciences, 18th Edition (Mack Publishing Company 1990)). The chimeric construct can also be conjugated to polyethylene glycol (PEG) to improve stability and extend bioavailability times (*e.g.,* Katre et al.; U.S. Patent 4,766,106).

The vaccines of this invention may be administered parenterally. The usual modes of administration of the vaccine are intramuscular, sub-cutaneous, and intra-peritoneal injections. Moreover, the administration may be by continuous infusion or by single or multiple boluses.

The gene gun has also been used to successfully deliver plasmid DNA for inducing immunity against an intracellular pathogen for which protection primarily depends on type 1 CD8.sup. + T-cells. (Kaufmann *et al.* (1999) *J. Immun.* 163(8): 4510-4518).

Gene transfer-mediated vaccination methods have become a rapidly expanding field and the compositions of the present invention are applicable to the treatment of both noninfectious and infectious diseases and noninfectious diseases, including but not limited to genetic disorders, using such vaccination methods. (See *e.g., Eck et al.* (1996) Gene-Based Therapy, In: Goodman & Gilman's The Pharmacological Basis of Therapeutics, Ninth Edition, Chapter 5, McGraw Hill).

Alternatively, the vaccine of the present invention, particularly as regards use of Flagellin as a PAMP, may be formulated and delivered in a manner designed to evoke an immune response at a mucosal surface. Thus, the vaccine compositions may be administered to mucosal surfaces by, for example, nasal or oral (intragastric) routes. Other modes of administration include suppositories and oral formulations. For suppositories, binders and carriers may include polyalkalene glycols or triglycerides. Oral formulations may include normally employed incipients such as pharmaceutical grades of saccharine, cellulose and magnesium carbonate. These compositions can take the form of solutions, suspensions, tablets, pills, capsules, sustained release formulations or powders and contain about 1 to 95% of the chimeric construct. The vaccines are administered in a manner compatible with the dosage formulation, and in such amount as will be therapeutically effective, protective and immunogenic dosages.

The quantity of vaccine employed will of course vary depending upon the patient's age, weight, height, sex, general medical condition, previous medical history, the condition being treated and its severity, and the capacity of the individual's immune system to synthesize antibodies, and produce a cell-mediated immune

response. Typically, it is desirable to provide the recipient with a dosage of the chimeric construct which is in the range of from about 1 μg agent /kg body weight of patient to 100 mg agent/kg body weight of patient, although a lower or higher dosage may also be administered. Precise quantities of the active ingredient, however, depend on the judgment of the practitioner. Suitable dosage ranges are readily determinable by one skilled in the art and may be on the order of nanograms of the chimeric construct to grams of the chimeric construct, depending on the particular construct. Preferably the dosage range of the active ingredient is nanograms to micrograms; more preferably nanograms to milligrams; and most preferably micrograms to milligrams. Suitable regimes for initial administration and booster doses are also variable, but may include an initial administration followed by subsequent administrations. The dosage may depend on the route of administration and will vary according to the size of the subject.

The present invention encompasses vaccines containing antigen and PAMPs from a single organism, such as from a specific pathogen. The present invention also encompasses vaccines that contain antigenic material from several different sources and/or PAMP material isolated from several different sources. Such combined vaccines contain, for example, antigen and PAMPs from various microorganisms or from various strains of the same microorganism, or from combinations of various microorganisms.

For purposes of therapy, the antigen/PAMP fusion proteins are administered to a mammal in a therapeutically effective amount. A vaccine preparation is said to be administered in a "therapeutically effective amount" if the amount administered is can

produce a measurable positive effect in a recipient. In particular, a vaccine preparation of the present invention produces a positive effect in a recipient if it invokes a measurable humoral and/or cellular immune response in the recipient. In particular, this invention contemplates a desirable therapeutically effective amount as one in which the vaccine invokes in the recipient a measurable humoral and/or cellular immune response versus the target antigen but causes neither excessive non-specific inflammation nor an autoimmune response versus non-target antigen(s).

As used herein, the term "treatment" refers to both therapeutic treatment and prophylactic or preventative treatment. In one embodiment, the present invention contemplates using the disclosed vaccines to treat patients in need thereof. The patients may be suffering from diseases such as, but not limited to, cancer, allergy, infectious disease, autoimmune disease, neurological disease, cardiovascular disease, or a disease associated with an allergic reaction. In another embodiment, the present invention contemplates administering the disclosed vaccines to passively immunize patients against diseases such as but not limited to, cancer, allergy, infectious disease, autoimmune disease, neurological disease, cardiovascular disease, or disease associated with an allergic reaction. In yet another embodiment the present invention contemplates administering the disclosed vaccines to immunize patients against diseases in addition to those cited in the previous sentence in which the objective is to rid the body of specific molecules or specific cells. A non-limiting example might be the removal or prevention of deposition of plaque in cardiovascular disease.

K. Treatment/Enhancement of Immunity

The vaccines of the present invention can be used to enhance the immunity of animals, more specifically mammals, and even more specifically humans (*e.g.*, patients) in need thereof. Enhancement of immunity is a desirable goal in the treatment of patients diagnosed with, for example, cancer, immune deficiency syndrome, certain topical and systemic infections, leprosy, tuberculosis, shingles, warts, herpes, malaria, gingivitis, and atherosclerosis.

The advantages of the vaccines of the present invention are that they induce a strong immune response against the target antigen with minimal undesired inflammatory reaction, as well as minimal instances of autoimmune disease. Such a reduced side effect profile has a distinct advantage over other vaccine approaches, particularly with respect to targeting of self antigens, because with many other vaccine strategies, in order to elicit a robust response against the self antigen, strong adjuvants are used and they result in excessive inflammation and can increase the risk of autoimmune disease.

As used herein, "immunoenhancement" refers to any increase in an organism's capacity to respond to foreign antigens or other targeted antigens, such as those associated with cancer, which includes an increased number of immune cells, increased activity and increased ability to detect and destroy such antigens, in those cells primed to attack such antigens.

The strength of an immune response can be measured by standard tests including, but not limited to, the following: direct measurement of peripheral blood lymphocytes by means known to the art; natural killer cell cytotoxicity assays (Provinciali *et al.* (1992) *J. Immunol. Meth.* 155: 19-24), cell proliferation assays

(Vollenweider *et al.* (1992) *J. Immunol. Meth.* 149: 133-135), immunoassays of immune cells and subsets (Loeffler *et al.* (1992) *Cytom.* 13: 169-174; Rivoltini *et al.* (1992) *Can. Immunol. Immunother.* 34: 241-251); and skin tests for cell- mediated immunity (Chang *et al.* (1993) *Cancer Res.* 53: 1043-1050). For an excellent text on methods and analyses for measuring the strength of the immune system, see, for example, Coligan *et al.* (Ed.) (2000) *Current Protocals in Immunology,* Vol. 1, Wiley & Sons.

Any statistically significant increase in the strength of immune response, as measured by the above tests, is considered "enhanced immune response" or "immunoenhancement". An increase in T-cells in S-phase of greater than 5 percent has been achieved by the methods of this invention. Enhanced immune response is also indicated by physical manifestations such as fever and inflammation, although one or both of these manifestations might not be observed with the recombinant vaccines of the present invention. Enhanced immune response is also characterized by healing of systemic and local infections, and reduction of symptoms in disease, *e.g.* decrease in tumor size, alleviation of symptoms of leprosy, tuberculosis, malaria, naphthous ulcers, herpetic and papillomatous warts, gingivitis, atherosclerosis, the concomitants of AIDS such as Kaposi's sarcoma, bronchial infections, and the like.

L. Vaccine Production

The procedures of the present invention can be used to generate a chimeric construct comprising one or more antigens of interest and one or more PAMPs. A small, non-immunogenic epitope tag (such as a His tag) can be added to facilitate the purification of fusion protein expressed in bacteria. The combination of antigen with

a PAMP such as BLP or Flagellin provides signals necessary for the activation of the antigen-specific adaptive and innate immune responses.

A large number of differing fusion proteins comprising different combinations of antigens and PAMPs can be readily generated using recombinant DNA technology or conjugation chemistry that is well known in the art. Virtually any antigen can be used to generate a vaccine by this approach using the same technology. This novel approach, therefore, is very versatile.

Large amounts of recombinant vaccine product can be generated using a bacterial expression system. The product can be purified from bacterial cultures using standard techniques. The approach is thus extremely economical and cost efficient. Alternatively, recombinant vaccine product can be produced and purified from cultures of yeast or other eukaryotic cells including, without limitation, insect cells or mammalian cells. Conjugated non-protein vaccine product can also be produced chemically in relatively large amounts. This is particularly the case if the PAMP and the antigen can both be obtained by relatively straightforward purification procedures and then conjugated together with relatively simple and efficient conjugation chemistry.

Alternatively, a chimeric construct containing a protein component and a non-protein component can be conveniently obtained by preparing the protein component by recombinant means and the non-protein component by chemical means and then linking the two components with linker chemistry well known in the art, some of which is described herein. Additionally, since the antigens and PAMPs contemplated in this invention can be naturally occurring, they can be purified from their natural

sources and then linked together chemically. Both T-cell and B-cell antigens can be used to generate vaccines by this approach.

Fusion of an antigen with a PAMP such as BLP or Flagellin optimizes the stoichiometry of the two signals thus minimizing the unwanted excessive inflammatory responses (which occur, for example, when antigens are mixed with adjuvants to increase their immunogenicity).

Fusion of an antigen with a PAMP such as BLP increases the likelihood that APCs activated in response to the vaccine productively trigger the desired adaptive immune response. Activation of such APCs in the absence of uptake and presentation of the antigen can lead to the induction of autoimmune responses, which, again, is one of the problems with commonly used adjuvants that prevents or limits their use in humans.

In a preferred embodiment, the fusion proteins of the present invention comprise an antigen or an immunogenic portion thereof which has been modified to contain an amino acid sequence comprising a leader sequence and a consensus sequence, that results in the post-translational modification of the consensus sequence or a portion of that sequence, wherein the post-translationally modified sequence is a ligand for a PRR. The modified antigens include, but are not limited to, antigens that contain the bacterial lipidation consensus sequence CXXN (SEQ ID NO: 1), wherein X is any amino acid, but preferably serine. Numerous leader sequences are well known in the art, but a preferred leader sequence is described by the first 20 amino acids of SEQ ID NO: 2, wherein the first 20 amino acids of SEQ ID NO: 2 are set forth in set forth in SEQ ID NO: 3. Examples of additional suitable leader sequences

are described in the Sequence Listing as SEQ ID NO: 4-7. A preferred chimeric construct comprises a leader sequence fused, in frame, to a sequence comprising the bacterial lipidation consensus sequence of SEQ ID NO: 1 further fused to an antigen (*e.g.* leader sequence—CXXN—antigen). Although this modification of the antigen can be referred to as a fusion, this modification can be achieved without fusing DNA, but rather by introducing, by mutagenesis, a leader sequence followed by the CXX sequence into DNA encoding any antigen of interest. Expression of a nucleic acid molecule encoding this chimeric construct, in a bacterial host cell, produces a substrate, first for bacterial proteases, that cleave the leader sequence from the modified antigen, and bacterial lipid transferases, which lipidate the sequence, or a portion thereof, comprising the lipidation consensus sequence. The resultant product is a chimeric construct or fusion protein that is a ligand for a PRR and is capable of stimulating both the innate and adaptive immune systems. In an additional embodiment, this chimeric construct or fusion protein comprises additional polar or charged amino acids to increase the hydrophilicity of the chimeric construct or fusion protein without altering the immunogenic or immunostimulatory properties of the construct.

Without further description, it is believed that one of ordinary skill in the art can, using the preceding description and the following illustrative examples, practice the methods of the present invention. The following working examples, therefore, specifically point out the preferred embodiments of the present invention, are illustrative only, and are not to be construed as limiting in any way the remainder of

the disclosure. Other generic and specific configurations will be apparent to those persons skilled in the art.

EXAMPLES

Example 1. Model Vaccine Cassette with an Antigen Domain and a PAMP Domain

In order to produce a model vaccine cassette of the present invention, we fused a pathogen-associated molecular pattern (PAMP) to the characterized mouse antigen, Eα. The PAMP we selected, BLP, is known to stimulate innate immune responses through the receptor, Toll-like-receptor-2 (TLR-2).

The protein sequence of the bacterial lipoprotein (BLP) used in the vaccine cassette for fusion with an antigen of interest is as follows: MKATKLVLGAVILGSTLLAGCSSNAKIDQLSSDVQTLNAKVDQLSNDVNAM RSDVQAAKDDAARANQRLDNMATKYRK (SEQ ID NO: 2). The leader sequence includes amino acid number 1 through amino acid number 20 of SEQ ID NO: 2. The first cysteine (amino acid number 21 of SEQ ID NO: 2) is lipidated in bacteria. This lipidation, which can only occur in bacteria, is essential for BLP recognition by Toll and TLRs. The C-terminal lysine (amino acid number 78 of SEQ ID NO: 2) was mutated to increase the yield of a recombinant vaccine, because this lysine can form a covalent bond with the peptidoglycan.

To assist in identification and purification of the antigen, a hexa-histidine tag was engineered on the C-terminal of the protein. The final construct is shown in Figure 3.

The fusion protein was expressed in bacteria and induced with IPTG. The protein was purified by lysis and sonication in 8 M Urea, 20 mM Tris, 20 mM NaCl, 2% Triton-X-100, pH 8.0. The lysate was passed over a 100 ml Q-Sepharose ion exchange column in the same buffer and washed with 5 column volumes of 8 M Urea, 20 mM Tris, 20 mM NaCl, 0.2% Triton-X-100, pH 8.0. The protein was eluted by salt gradient (20 mM NaCl to 800 mM NaCl). Positive fractions were identified by immunoblotting using an antibody to the Histidine tag. These fractions were pooled and passed over a 2 ml nickel-agarose column. The column was extensively washed with the same buffer (10 column volumes) and then washed with 5 column volumes of phosphate buffer (20 mM) containing 200 mM NaCl, 0.2% Triton-X-100, 20 mM imidazole, pH 8.0. The purified protein was eluted in 20 mM phosphate buffer, 200 mM NaCl, 0.1% Triton-X-100, 250 mM imidazole and fractions were again tested for protein by immunoblotting. Positive fractions were pooled and dialyzed overnight against phosphate buffered saline containing 0.1% Triton-X-100. The sample was then decontaminated of any endotoxin by passage over a polymyxin B column, and concentrated in an Amicon concentrator by centrifugation and tested by immunoblotting and protein concentration for protein content.

Example 2. Stimulation of NF-κB by BLP/Eα model antigen in RAW cells

To test whether the model antigen could stimulate signal transduction pathways necessary for an immune response, we assayed NF-κB activation in the RAW mouse macrophage cell line *in vitro*. We developed a stable RAW cell line that harbors an NF-κB-dependent firefly luciferase gene. Stimulation of these cells with activators of NF-κB leads to production of luciferase which is measured in cell lysates

by use of a luminometer. Cells were stimulated with the indicated amounts of BLP/Eα left 5 hours and harvested for luciferase measurement.

As a control, RAW cells were stimulated with LPS in the presence and absence of polymyxin B (PmB). PmB inactivates endotoxin and as expected the activation of NF-κB activity in the LPS+PmB sample is diminished by 98%. BLP/Eα also activates NF-κB in a dose-dependent manner as shown in Figure 4, however, treatment with PmB does not inactivate the stimulus to a statistically significant degree. These results suggest that the activation of NF-κB seen with BLP/Eα is not due to contamination of the preparation with endotoxin.

Example 3. BLP/Eα Model Vaccine Induces the Production of IL-6 by Dendritic Cells *In Vitro*

An effective vaccine must be able to stimulate dendritic cells (DC)to mature and present antigen. To test whether BLP/Eα could induce DC function, we tested the ability of bone marrow-derived DC to produce IL-6 after stimulation in vitro. Bone marrow dendritic cells were isolated and grown for 5 days in culture in the presence of 1% GM-CSF. After 5 days, cells were replated at 250,000 cells/well in a 96-well dish and treated with either Eα peptide (0.3μg/ml), LPS (100ng/ml) + Eα peptide (0.3μg/ml), or BLP/Eα. BLP/Eα was able to stimulate IL-6 production in these cells as measured in a sandwich ELISA (Figure 5).

Example 4. BLP/Eα Stimulates Maturation of Immature Dendritic Cells

To determine whether BLP/Eα vaccine can be processed and presented by dendritic cells, we stimulated dendritic cells with the vaccine and tested them for the surface expression of B7.2 and Eα peptide bound to MHC Class II. Cultured bone

marrow-derived dendritic cells (5 days) were stimulated with Eα peptide or BLP/Eα and were stained with an antibody to the B7.2 costimulatory molecule and/or with Yae antibody which recognizes Eα peptide bound to MHC Class II. Analysis was performed by FACS (Figure 6).

Example 5. BLP/Eα Model Vaccine Stimulates Specific T-Cells In Vitro

We next assayed whether BLP/Eα that was processed and presented by DC could stimulate the proliferation of antigen-specific T-cells in vitro. Bone marrow derived mouse DC were isolated and plated into medium containing 1% GM-CSF at 750,000 cells/well. Cells were cultured for 6 days and then the DC were collected, washed, and counted then replated in 96-well dishes at 250,000 cells per well. Cells were stimulated with the above indicated antigens and left three days to mature. After 3 days, the DC were resuspended and plated in a 96-well dish at either 5,000 or 10,000 cells/well. T-cells from lymph nodes from a 1H3.1 TCR transgenic mouse (1H3.1 TCR is specific for the Eα peptide)were plated on the DC at 100,000 cells/well. Cells were left for 3 days in culture then "pulsed" with 0.5μCi/well of ^{3}H-thymidine. The cells were harvested 24 hours later and incorporation of thymidine (T-cell proliferation) was measured in cpm (Figure 7).

Example 6. BLP/Eα Activates Specific T-cells In Vivo

To assess the ability of the vaccine to generate a specific T-cell response in vivo, we injected the fusion protein into a mouse. Three mice were injected as follows:

Mouse #	Sample injected	# of lymph node cells
1	Eα peptide 30μg in PBS	$1.9x10^6$
2	Eα peptide 30μg in CFA*	$3.29x10^7$
3	BLP/ Eα 100μg	$5.2x10^6$

*Complete Freund's Adjuvant

The injected footpad of mouse #2 was considerably swollen for the duration of the experiment, but the footpads of mice #1 and #3 appeared normal. After 6 days, the mice were euthanized and the associated draining lymph node was harvested for a T-cell proliferation assay. T-cells were plated in a 96-well plate at 400,000 cells/well and were restimulated with either Eα peptide or with BLP/Eα at the indicated doses. Cells were left 48 hours to begin proliferation, pulsed with 0.5μCi/well of ^{3}H-Thymidine in medium and harvested 16 hours later. Thymidine incorporation was measured by counting in a beta-plate reader (Figure 8).

Example 7. Model Vaccine Cassette with an Allergen-Related Antigen

Using the procedures set forth above for the production of the BLP/Eα model antigen, a vaccine cassette with an allergen-related antigen is produced using the pollen allergen Ra5G from the giant ragweed (*Ambrosia trifida*). The amino acid sequence of Ra5G is as follows:

MKNIFMLTLF ILIITSTIKA IGSTNEVDEI KQEDDGLCYE GTNCGKVGKY CCSPIGKYCVCYDSKAICNK NCT (SEQ ID NO: 9).

The amino acid sequence of this allergen can be fused with the BLP amino acid sequence (SEQ ID NO: 1) to generate the BLP/Ra5G fusion protein. The resultant recombinant vaccine places the allergen in the context of an IL-12 inducing signal, where the PAMP in this case is BLP).

When introduced into a subject, this vaccine will generate allergen-specific T-cell responses that will be differentiated into Th1 responses due to the induction of IL-12 by BLP in dendritic cells and macrophages.

Example 8. Model Vaccine Cassette with a Tumor-Related Antigen

Using the procedures set forth above for the production of the BLP/Eα model antigen, a vaccine cassette with a tumor-related antigen is produced using the model tumor antigen, Tyrosinase-Related Protein 2 (TRP-2). The nucleic acid sequence and corresponding amino acid sequence of TRP-2 is provided in SEQ ID NO: 10 (shown in Figure 20) and SEQ ID NO: 11 (shown in Figure 21), respectively. The region used for BLP fusion includes nucleic acid number 840 through nucleic acid number 1040 of SEQ ID NO: 10. The T-cell epitope includes nucleic acid number 945 through nucleic acid number 968 of SEQ ID NO: 10.

A region of the TRP-2 that can be used for the vaccine construction is shown below:

LDLAKKSIHPDYVITTQHWLGLLGPNGTQPQIANCSVYDFFVWLHYYS VRDTLLGPGRPYKAIDFSHQ (SEQ ID NO: 12).

A T-cell epitope of SEQ ID NO: 12 is VYDFFVWL (SEQ ID NO: 13).

Example 9: CpG Immunostimulation

The family of TLRs has recently been identified as an essential component of innate immune recognition in both *Drosophila* and mammalian organisms (Hoffmann *et al.* (1999) Science 284:1313-1318; Imler *et al.* (2000) *Curr. Opin. Microbiol.* 3:16-22). *Drosophila* Toll is required for the detection of fungal infection and the induction of the antifungal peptide drosomycin (Lemaitre *et al.* (1996) *Cell* 86:973-983). In the mouse, TLR2 and TLR4 were shown to mediate recognition of bacterial PGN and LPS, respectively (Takeuchi *et al.* (1999) *Immunity* 11:443-451). The functions of the other members of the *Drosophila* and mammalian Toll families are currently unknown, although it is expected that at least some of them are involved in innate immune recognition as well.

Collectively, the results described here indicate that the immunostimulatory effect of CpG-DNA on the three types of professional antigen presenting cells- DC, macrophages and B-cells -- is mediated by a MyD88 signaling pathway. MyD88 is involved in signal transduction by the Toll and IL-1 receptor families. The activities of the IL-1 family of cytokines, including IL-1 and IL-18, is dependent on processing by caspase-1, but in all the experiments described here, the absence of caspase-1 had no effect on CpG-DNA induced cellular responses (Fantuzzi *et al.* (1999) *J. Clin. Immunol.* 19:1-11).

We tested whether TLR2 and TLR4 are involved in the recognition of CpG-DNA and found that they are not, at least based on the assays provided herein. We believe, therefore, that CpG-DNA is recognized by a Toll receptor other than TLR2 and TLR4. Cell lines that express endogenous or transfected TLR1 through TLR6 did

not respond to CpG-DNA (data not shown), suggesting that some other member of the Toll family may mediate CpG-DNA recognition.

While the identity of the Toll receptor that is responsible for CpG-DNA recognition remains unknown at this point, the fact that CpG-DNA requires internalization to exert its stimulatory effect (Krieg *et al.* (1995) *Nature* 374:546-549; Stacey *et al.* (1996) *J. Immunol.* 157:2116-2122) suggests that the TLR that mediates the recognition may be expressed in an intracellular compartment, such as the late endosome, phagosome, or lysosome.

Example 10. CpG and B-Cell Activation

B-cells from the indicated mouse strains were purified from spleen by complement kill of $CD4^+$, $CD8^+$ and macrophages. Non-adherent cells were cultured in the presence or absence of different amounts of stimulating CpG-DNA (5'-TCCATGACGTTCCTGACGTT-3' (SEQ ID NO. 8), phosphorothioate modified) at 1×10^6 cells/ml. After 48 h, the cells were pulsed with [^{3}H]thymidine (0.5μCi per well, NEN) for 16 h and processed for beta counting.

Results shown in Figure 9A are representative of three independent experiments. B-lymphocytes derived from caspase-1 knock-out mice proliferated in response to CpG comparably to wild type cells (Figure 9A), suggesting that the effect of the MyD88 deletion is not due to a defect in IL-1/IL-18 mediated signaling. This result indicates that CpG-DNA signals through the receptors of the Toll family. B-cells from two available TLR-deficient mouse strains, the C57BL/10ScCr strain that carries a spontaneous deletion of the TLR4 gene (Poltorak *et al.* (1998) *Science* 282:2085-2088; Qureshi *et al. J. Exp. Med.*1999, 189:615-625) and TLR2 knock-out

mouse (Takeuchi *et al.* (1999) *Immunity* 11:443-451), both proliferated in response to CpG similar to the wild-type cells (Figure 9A). This result, together with the normal responses of the caspase-1 deficient cells, suggested that a member(s) of the Toll family other than TLR2 or TLR4 is involved in recognition of CpG-DNA.

Example 11. CpG and B-cell Expression of CD86 and MHC class II

The CpG-induced expression of CD86 and upregulation of MHC class-II molecules on B-cells was tested to determine whether these processes are mediated by the MyD88 signaling pathway. B-lymphocytes from MyD88 knock-out mice and wild-type littermate control mice, as well as those from TLR4-deficient mice, were stimulated by CpG-DNA. CD86 and MHC class -II cell surface expression were analyzed by FACS.

B-cells were prepared as above and cultured at 3 x 10^6 cells/ml with or without 10 mM CpG for 12 h. After the stimulation, the surface expression of CD86 and MHC class II were analyzed by flow cytometry. Results, shown in Figure 9B, represent gated B-cells. The shaded area represents stimulated cells, whereas the unshaded area represents untreated controls. As shown in Figure 9B, CpG-DNA strongly induced expression of CD86 and MHC class-II on B-cells from wild-type and TLR4-deficient mice. By contrast, this induction was completely abrogated in MyD88 deficient B-lymphocytes.

Example 12. Cloning of Salmonella Tymphimurium Flagellin and E. coli Flagellin

Full-length *Salmonella typhimurium* Flagellin and *E coli* Flagellin were cloned from the respective genomic DNAs and expressed as recombinant proteins in *E coli* . Flagellin was expressed alone, or as a fusion protein with antigenic epitopes from ovalbumin (SIINFEKL), tyrosinase-2 protein (TRP2) cloned from murine B16 cells, or the C-terminal fragment of I-Eα protein, which contains the Eα epitope. In addition, all of the recombinant proteins contained a C-terminal 6x-histidine repeat to aid in purification.

Induced bacteria were lysed in a gentle lysis buffer containing Triton-X 100, glycerol, imidazole, NaCl, and Tris, pH=8.0 to maintain the native conformation of the proteins. Fusion proteins were purified by passing filtered lysates over a Nickel-NTA agarose column followed by extensive washes in several buffers containing imidazole. Purified proteins were eluted in 250mM imidazole, passed twice over a Polymyxin B column to remove contaminating lipopolysaccharide and then dialyzed extensively overnight in PBS at 4°C. The resulting purified proteins were very stable and retain activity at 4°C for at least a month.

Example 13. Flagellin In vitro Assays

In vitro assays were performed using purified Flagellin fusion proteins as follows:

The human 293 cell line and the murine RAW cell line were stably transfected with a reporter gene containing two copies of the Igκ NF-κB site driving transcription

of luciferase (this construct is referred to as "pBIIxluc"). The resulting cell lines (293LUC and RAWkb) were plated in 24-well dishes and treated 24 hours later with Flagellin fusion proteins or a control protein (lacZ) that was made in the same vector and purified exactly the same way as the Flagellin proteins. Cell lysates were made after 5 hours of treatment and were tested for luciferase activity to indicate induction of NF-κB. The Flagellin proteins significantly induced NF-κB in this assay, particularly in 293 cells whereas the control protein had no effect, as shown in Figures 12 and 13. It is believed that this induction was not due to contamination by LPS since polymyxin B did not inhibit the activation in RAWκB cells, and 293LUC cells do not respond to LPS but do respond to Flagellin, as indicated by Figures 12 and 14.

The results of the In vitro assays demonstrate that Flagellin fusion proteins retain their ability to stimulate Toll-Like Receptors and can therefore be used for the generation of recombinant Flagellin-Antigen fusion proteins for the purpose of vaccination. In Flagellin-Antigen fusion proteins, Flagellin is believed to stimulate the innate immune system by triggering Toll-Like Receptors, whereas the antigen fused to Flagellin provides epitopes for recognition by T and B lymphocytes.

Example 14: CpG and IL-6 Production in Macrophages

Adherent thioglycollate-elicited peritoneal exudate cells (PECs) from the indicated mouse strains were treated with different stimuli for 24 h. The release of IL-6 into the supernatant was analyzed by specific enzyme-linked immunosorbent assay (ELISA) using anti-mouse IL-6 monoclonal antibodies. As CpG-DNA is also known to have a pronounced stimulatory effect on macrophages (Stacey *et al.* (2000) *Curr. Top. Microbiol. Immunol.* 247: 41-58; Lipford *et al.* (1998) *Trends Microbiol.* 6: 496-

500; Stacey *et al.* (1996) *J. Immunol.* 157: 2116-2122), CpG-induced expression of IL-6 by wild-type and MyD88 was examined in deficient macrophages. Cells derived from caspase-1 knock-out mice were used as a control for IL-1-mediated induction of IL-6. The production of IL-6 in response to CpG stimulation was completely abolished in MyD88 -/- macrophages, but was normal in caspase-1, TLR2- and TLR4-deficient cells (Figure 10A). Oligonucleotides consisting of inverted CpG sequence (GpC) were used as a control, and as expected did not induce detectable amounts of IL-6 (Figure10A).

Example 15. CpG-DNA-Induced IκBα Degradation

We next tested whether activation of the NF-κB signaling pathway is deficient in MyD88 -/- macrophages. Peritoneal macrophages were stimulated with CpG-DNA, or LPS as a control, for 0, 10, 20, 60, and 90 minutes and lysed thereafter. For each timepoint, 30 mg total protein was processed for SDS-PAGE and analyzed by immunoblotting for IκBα protein. (Figure 10B). In wild-type cells, both LPS and CpG-DNA induced NF-κB activation, as evidenced by the degradation of IκB protein (Figure 10B). In MyD88 -/- macrophages, LPS still induced IκB degradation, albeit with delayed kinetics, as is consistent with published observations (Kawai *et al.* (1999) *Immunity* 11: 115-122). However, unlike LPS, CpG-DNA did not induce IκB degradation in MyD88 -/- macrophages (Figure 10B). Therefore, while both LPS and CpG-DNA signal through MyD88, the signaling pathways initiated by these stimuli are not identical, reflecting a possibility that different TLRs can activate overlapping but distinct signaling pathways.

Example 16. CpG and IL-2 Production in Dendritic Cells

CpG-DNA has been shown to be a potent inducer of DC activation (Sparwasser *et al.* (1998) *Eur. J. Immunol.* 28: 2045-2054). DC play a pivotal role in the initiation of the adaptive immune responses (Banchereau *et al.* (1998) *Nature* 392: 245-252). Upon interaction with microbe-derived products (PAMPs) in peripheral tissues, DC undergo developmental changes collectively referred to as maturation (Banchereau *et al.* (1998) *Nature* 392: 245-252). The hallmark of DC maturation is the induction of cell surface expression of CD80 and CD86 molecules, as well as migration into lymphoid tissues and production of cytokines such as IL-12 (Banchereau *et al.* (1998) *Nature* 392: 245-252). We tested therefore, whether the induction of DC maturation by CpG-DNA is mediated by the MyD88 signaling pathway. MyD88 -/- animals produce IL-12 when stimulated with CpG oligonucleotides. Wild-type, B10/ScCr, and MyD88 -/- bone marrow DC, were prepared from bone marrow suspensions cultured for 5 days in DC Growth Medium (RPMI 5% FC + 1% GM-CSF) and stimulated with 10 mm CpG or 10 mm GpC oligonucleotides or left untreated. Supernatants were taken 24 h and 48 h after stimulation and analyzed for IL-12 by ELISA using specific capture and detection antibodies.

The results, shown in Figure 11, are from one of three independently performed experiments. Consistent with published reports, CpG-DNA induced secretion of large amounts of IL-12 by DC from the wild-type mice. However, no detectable IL-12 was produced in response to CpG stimulation by DC derived from MyD88 knock-out mice (Figure 11). As expected, DC from TLR4-deficient mice produced wild-type levels of IL-12 in response to CpG-DNA (Figure 11).

Example 17. CpG/ Eα Chimeric Construct

A non-protein PAMP, CpG, was conjugated to the characterized mouse antigen, Eα, through a PEG polymer linker and/or copolymers of D-lysine and D-glutamate, according to the methods described in U.S. Pat. No. 6,06,0056. A CpG-DNA derivative, comprising CpG_{40} was used as the non-protein PAMP.

All articles, patents and other materials referred to below are specifically incorporated herein by reference.

While this invention has been disclosed with reference to specific embodiments, it is apparent that other embodiments and variations of this invention may be devised by others skilled in the art without departing from the true spirit and scope of the invention. The appended claims are intended to be construed to include all such embodiments and equivalent variations.

I CLAIM:

1. A fusion protein comprising an isolated PAMP or an immunostimulatory portion or immunostimulatory derivative thereof and an antigen or an immunogenic portion or immunogenic derivative thereof.

2. The fusion protein of claim 1, wherein the PAMP is selected from the group consisting of peptides, proteins, lipoproteins and glycoproteins.

3. The fusion protein of claim 1, wherein the PAMP is a ligand for a PRR.

4. The fusion protein of claim 1, wherein the antigen is obtainable from sources selected from the group consisting of bacteria, viruses, fungi, yeast, protozoa, metazoa, tumors, malignant cells, abnormal neural cells, arthritic lesions, cardiovascular lesions, plants, animals, humans, allergens, and hormones.

5. The fusion protein of claim 1, wherein the antigen is microbe-related, allergen-related or related to abnormal human or animal cells.

6. The fusion protein of claim 1, wherein the PAMP and antigen are linked by a chemical linker.

7. The fusion protein of claim 1, wherein the fusion protein further comprises one or more additional PAMPs or immunostimulatory portions or immunostimulatory derivatives thereof, and wherein the PAMPs, immunostimulatory portions or immunostimulatory derivatives of the fusion protein are either identical or different.

8. The fusion protein of claim 1, wherein the vaccine further comprises one or more additional antigens or immunogenic portions or immunogenic derivatives thereof, and wherein the antigens, immunogenic portions or immunogenic derivatives of the fusion protein are either identical or different.

9. The fusion protein of claim 1, wherein the fusion protein further comprises one or more additional PAMPs or immunostimulatory portions or immunostimulatory derivatives thereof, and one or more additional antigens or immunogenic portions or immunogenic derivatives thereof, and wherein the

PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, and/or the antigens , immunogenic portions or immunogenic derivatives of the fusion protein are either identical or different.

10. The fusion protein of claim 1, wherein the fusion protein further comprises one or more carrier proteins.

11. The fusion protein of claim 1, wherein the PAMP and the antigen are separated by a spacer.

12. The fusion protein of claim 1, wherein the PAMP is BLP.

13. The fusion protein of claim 12, wherein BLP is the amino acid sequence of SEQ ID NO: 2.

14. The fusion protein of claim 1, wherein the antigen is selected from the group consisting of amyloid-β peptide, listeriolysin, HIV gp120 and p24, Ra5G and TRP-2, EGFR, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

15. The fusion protein of claim 1, wherein the PAMP is a peptide mimetic of a non-protein PAMP and/or the antigen is a peptide mimetic of a non-protein antigen.

16. A fusion protein comprising a leader sequence, a consensus sequence, and an antigen sequence, wherein the consensus sequence is either a glycosylation or lipidation consensus sequence.

17. The fusion protein of claim 16, wherein the consensus sequence is either a glycosylation or a lipidation consensus sequence.

18. The fusion protein of claim 16, wherein the leader sequence signals post-translational glycosylation or lipidation of the consensus sequence.

19. The fusion protein of claim 18, wherein the leader peptide is selected from the group consisting of:

a) the amino acid sequence of SEQ ID NO: 3;

b) the amino acid sequence of SEQ ID NO: 4;

c) the amino acid sequence of SEQ ID NO: 5;

d) the amino acid sequence of SEQ ID NO: 6; and

e) the amino acid sequence of SEQ ID NO: 7.

20. The fusion protein of claim 16, wherein the consensus sequence is CXXN (SEQ ID NO: 1).

21. The fusion protein of claim 17, wherein the consensus sequence is CXXN (SEQ ID NO: 1).

22. The fusion protein of claim 16, wherein the antigen is obtainable from sources selected from the group consisting of bacteria, viruses, fungi, yeast, protozoa, metazoa, tumors, malignant cells, abnormal neural cells, arthritic lesions, cardiovascular lesions, plants, animals, humans, allergens, and hormones.

23. The fusion protein of claim 16, wherein the antigen is microbe-related, allergen-related or related to abnormal human or animal cells.

24. A recombinant vector comprising nucleotides encoding the fusion protein of claim 1 or claim 16.

25. A host cell comprising the recombinant vector of claim 24.

26. The host cell of claim 25, wherein the host cell is that of a host selected from the group consisting of bacteria, yeast, plants, animals and insects.

27. The host cell of claim 25, wherein the host cell is a bacteria which produces the PAMP naturally.

28. The host cell of claim 25, wherein the host cell is a bacteria that lipidates the PAMP.

29. A method of producing a fusion protein comprising a PAMP or an immunostimulatory portion or immunostimulatory derivative thereof and an antigen or an immunogenic portion or immunogenic derivative thereof, said method comprising culturing the cell of claim 16 and isolating the fusion protein produced by the cell.

30. A vaccine comprising the fusion protein of claim 1 or claim 16 and a pharmaceutically acceptable carrier.

31. The vaccine of claim 30, wherein the antigen is associated with disease.

32. The vaccine of claim 30, wherein the antigen is allergen-related or related to abnormal human or animal cells.

33. The vaccine of claim 30, wherein the antigen is a hormone.

34. The vaccine of claim 30, wherein the antigen is an amyloid-β peptide.

35. The vaccine of claim 30, wherein the PAMP is a peptide mimetic of a non-protein PAMP.

36. The vaccine of claim 30, wherein the antigen is a peptide mimetic of a non-protein antigen.

37. A method of immunizing an animal comprising the step of administering to the animal the vaccine of claim 30.

38. A method of immunizing a mammal comprising the step of administering to the mammal the vaccine of claim 30.

39. The method of claim 38, wherein the mammal is a human.

40. The method of claim 37, wherein the vaccine is administered parenterally, intravenously, orally, using suppositories, or via the mucosal surfaces.

41. The method of claim 39, wherein the antigen is amyloid-β peptide or an immunogenic portion thereof.

42. The method of claim 39,wherein the fusion protein is administered to a human diagnosed with Alzheimer's disease.

43. A method of treating a subject comprising the steps of administering antibodies or activated immune cells to a subject and administering a vaccine comprising the fusion protein of claim 1 or claim 16, wherein the antibodies or activated immune cells are directed against the antigen of the fusion protein.

44. The method of claim 43, wherein the antibodies are monoclonal.

45. A method of treating a subject comprising the steps of administering a vaccine comprising the fusion protein of claim 1 or claim 16 and an agent selected from the group consisting of: chemotherapeutic agents and anti-angiogenic agents.

46. The method of claim 45, wherein the chemotherapeutic agent is an anti-cancer agent.

47. A method of treating a subject comprising the steps of administering a vaccine comprising the fusion protein of claim 1 or claim 16 in combination with surgery or radiation therapy.

48. A fusion protein comprising an isolated PAMP and an antigen, wherein the antigen is a self-antigen.

49. The fusion protein of claim 48, wherein the antigen is selected from the group consisting of amyloid-β peptide, TRP-2, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2,

HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

50. The fusion protein of claim 48, wherein the PAMP is selected from the group consisting of peptides, proteins, lipoproteins, and glycoproteins.

51. The fusion protein of claim 48, wherein the PAMP is a ligand for a PRR.

52. The fusion protein of claim 48, wherein the PAMP is lipidated.

53. The fusion protein of claim 48, wherein the antigen is obtainable from sources selected from the group consisting of tumors, malignant cells, abnormal neural cells, arthritic lesions, and cardiovascular lesions.

54. The fusion protein of claim 48, wherein the antigen is related to abnormal human or animal cells.

55. The fusion protein of claim 48, wherein the PAMP and antigen are linked by a chemical linker.

56. The fusion protein of claim 48, wherein the fusion protein further comprises one or more additional PAMPs, and wherein the PAMPs are either identical or different.

57. The fusion protein of claim 48, wherein the fusion protein further comprises one or more additional antigens, and wherein the antigens are either identical or different.

58. The fusion protein of claim 48, wherein the fusion protein further comprises one or more additional PAMPs and one or more additional antigens and wherein the PAMPs, and/or the antigens, are either identical or different.

59. The fusion protein of claim 48, wherein the fusion protein further comprises one or more carrier proteins.

60. The fusion protein of claim 48, wherein the PAMP and the antigen are separated by a spacer.

61. The fusion protein of claim 48, wherein the PAMP is a BLP, an OMP, an OSP, a Flagellin or a porin.

62. The fusion protein of claim 61, wherein the PAMP is the BLP which has the amino acid sequence of SEQ ID NO: 2.

63. The fusion protein of claim 48, wherein the PAMP is a peptide mimetic of a non-protein PAMP and/or the antigen is a peptide mimetic of a non-protein antigen.

64. A method of stimulating an innate immune response in an animal and thereby enhancing the adaptive immune response to a foreign or self-antigen which comprises co-administering a PAMP with the foreign or self antigen.

65. The method of claim 64 wherein the innate immune response is stimulated by activating one or more of the Toll-like Receptors.

66. The method of claim 65 wherein the animal is a mammal.

67. The method of claim 66 wherein the adaptive immune response is enhanced by the activation of APCs by the activation of the one or more Toll-like Receptors.

68. The method of claim 67 wherein the antigen is of bacterial, viral, protozoan, metazoan, or fungal origin.

69. The method of claim 68 wherein the PAMP and antigen are co-administered in the form of a fusion protein.

70. The method of claim 69 wherein the PAMP is selected from the group consisting of: bacterial lipoprotein, bacterial outer membrane protein, bacterial outer surface protein, Flagellins, or porins.

71. The method of claim 70 wherein the PAMP is selected from the group consisting of: Borrelia ospA, Borrelia ospB, Borrelia ospC, the lipidated tetrapeptide of bacterial lipoprotein and Klebsiella ompA.

72. The method of claim 71 wherein the PAMP is the lipidated tetrapeptide of bacterial lipoprotein.

73. The method of claim 70 wherein the self-antigen is selected from the group consisting of amyloid-β peptide, TRP-2, EGFR, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

74. The method of claim 67 wherein the antigen is a self-antigen.

75. The method of claim 73 wherein the PAMP and antigen or co-administered in the form of a fusion protein.

76. The method of claim 74 wherein the PAMP is selected from the group consisting of: bacterial lipoprotein, bacterial outer membrane protein, bacterial outer surface protein, Flagellins, or porins.

77. The method of claim 75 wherein the PAMP is selected from the group consisting of: Borrelia ospA, Borrelia ospB, Borrelia ospC, the lipidated tetrapeptide of bacterial lipoprotein and Klebsiella ompA.

78. The method of claim 77 wherein the PAMP is the lipidated tetrapeptide of bacterial lipoprotein.

79. The method of claim 75 wherein the self-antigen is selected from the group consisting of amyloid-β peptide, TRP-2, EGFR, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

80. The method of claim 69 wherein the fusion protein is formulated with a pharmaceutically acceptable adjuvant.

81. The fusion protein of claim 48, wherein the antigen is selected from the group of antigens consisting of vascular endothelial growth factors, vascular endothelial growth factor receptors, fibroblast growth factors and fibroblast growth factor receptors.

82. A vaccine which comprises a PAMP conjugated with a foreign or self antigen that stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

83. A vaccine which comprises a PAMP conjugated with a foreign or self antigen which, when administered at a therapeutically active dose, stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

84. A method of treatment comprising the steps of administering to an individual a vaccine which comprises a PAMP conjugated with a foreign or self antigen

which stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

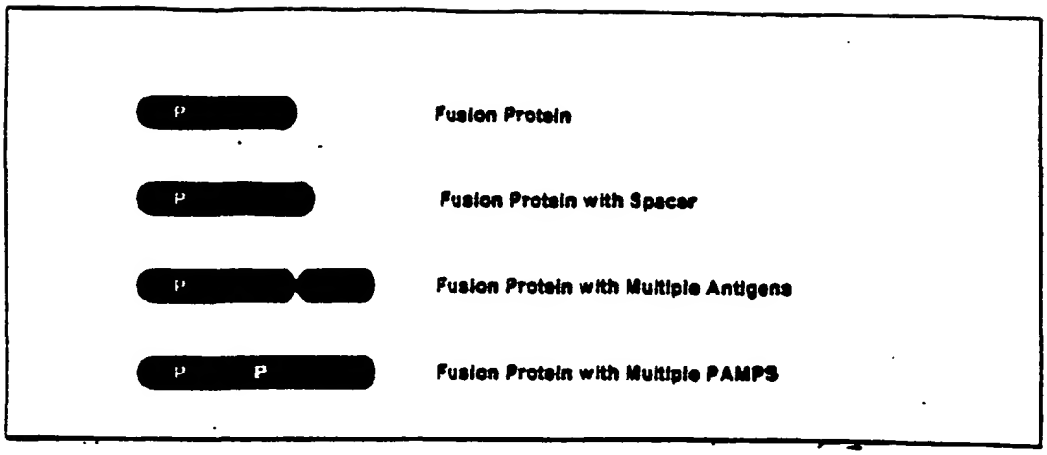
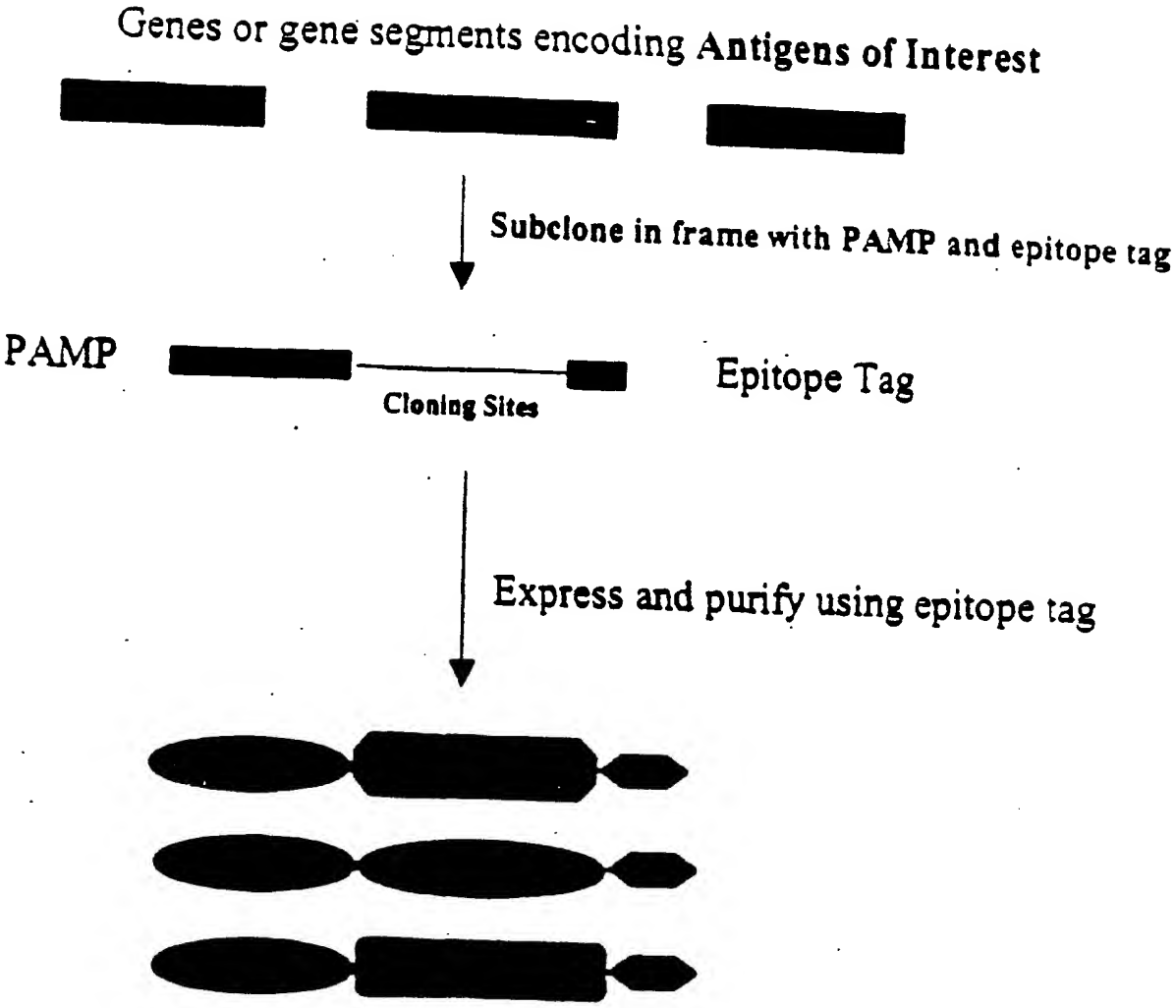

P
Fusion Protein
P
Fusion Protein with Spacer
P
Fusion Protein with Multiple Antigens
P P
Fusion Protein with Multiple PAMPS

Figure 1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Subclone in frame with PAMP and epitope tag
PAMP
Cloning Sites
Epitope Tag
Express and purify using epitope tag

Figure 2

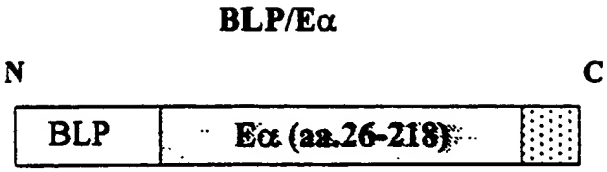

Figure 3

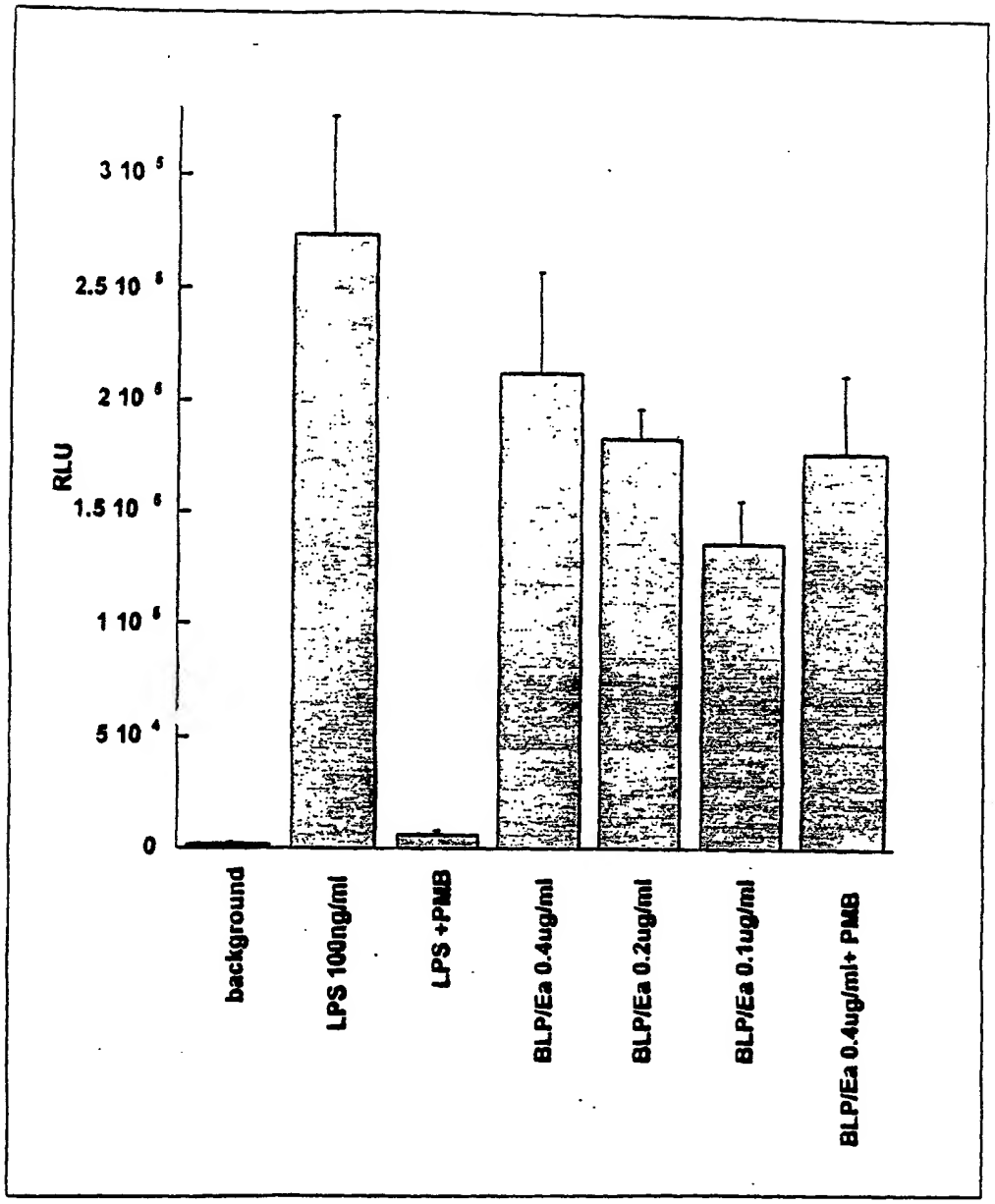
RLU
3 10 5
2.5 10 5
2 10 5
1.5 10 5
1 10 5
5 10 4
0
background
LPS 100ng/ml
LPS +PMB
BLP/Ea 0.4ug/ml
BLP/Ea 0.2ug/ml
BLP/Ea 0.1ug/ml
BLP/Ea 0.4ug/ml+ PMB

Figure 4

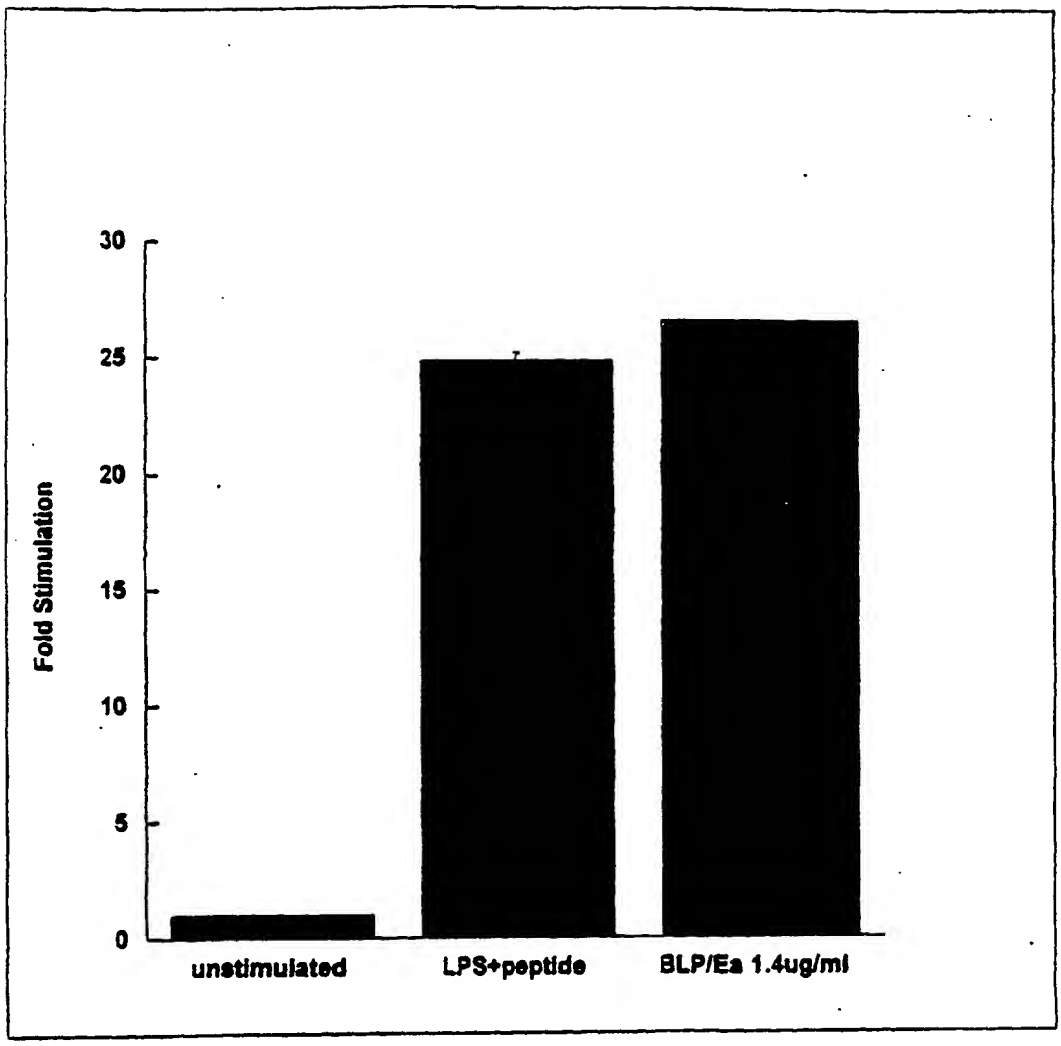
30
25
20
15
10
5
0
Fold Stimulation
unstimulated
LPS+peptide
BLP/Ea 1.4ug/ml

Figure 5

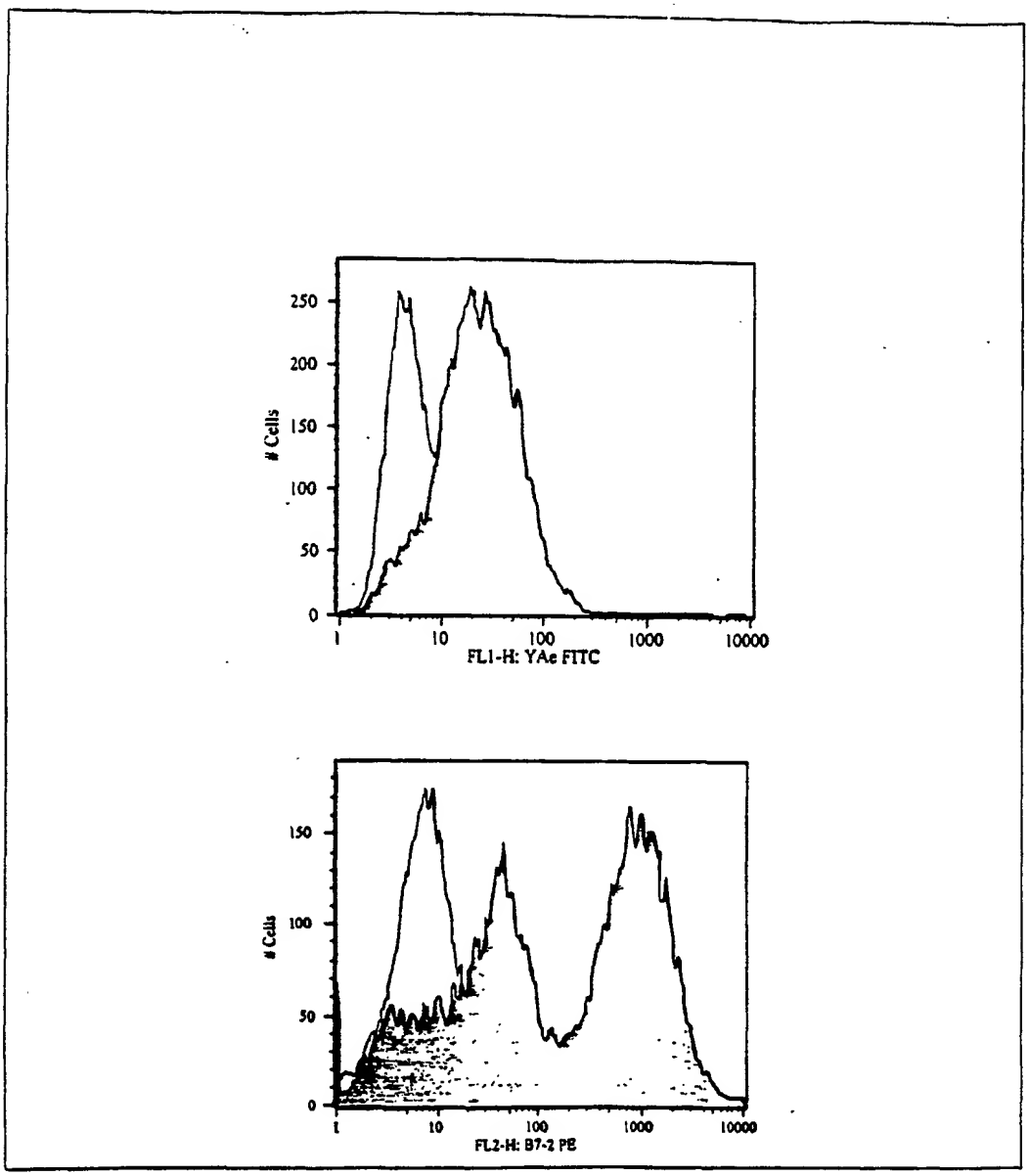
250
200
150
100
50
0
Cells
1
10
100
1000
10000
FL1-H: YAe FITC
150
100
50
0
Cells
1
10
100
1000
10000
FL2-H: B7-2 PE

Figure 6

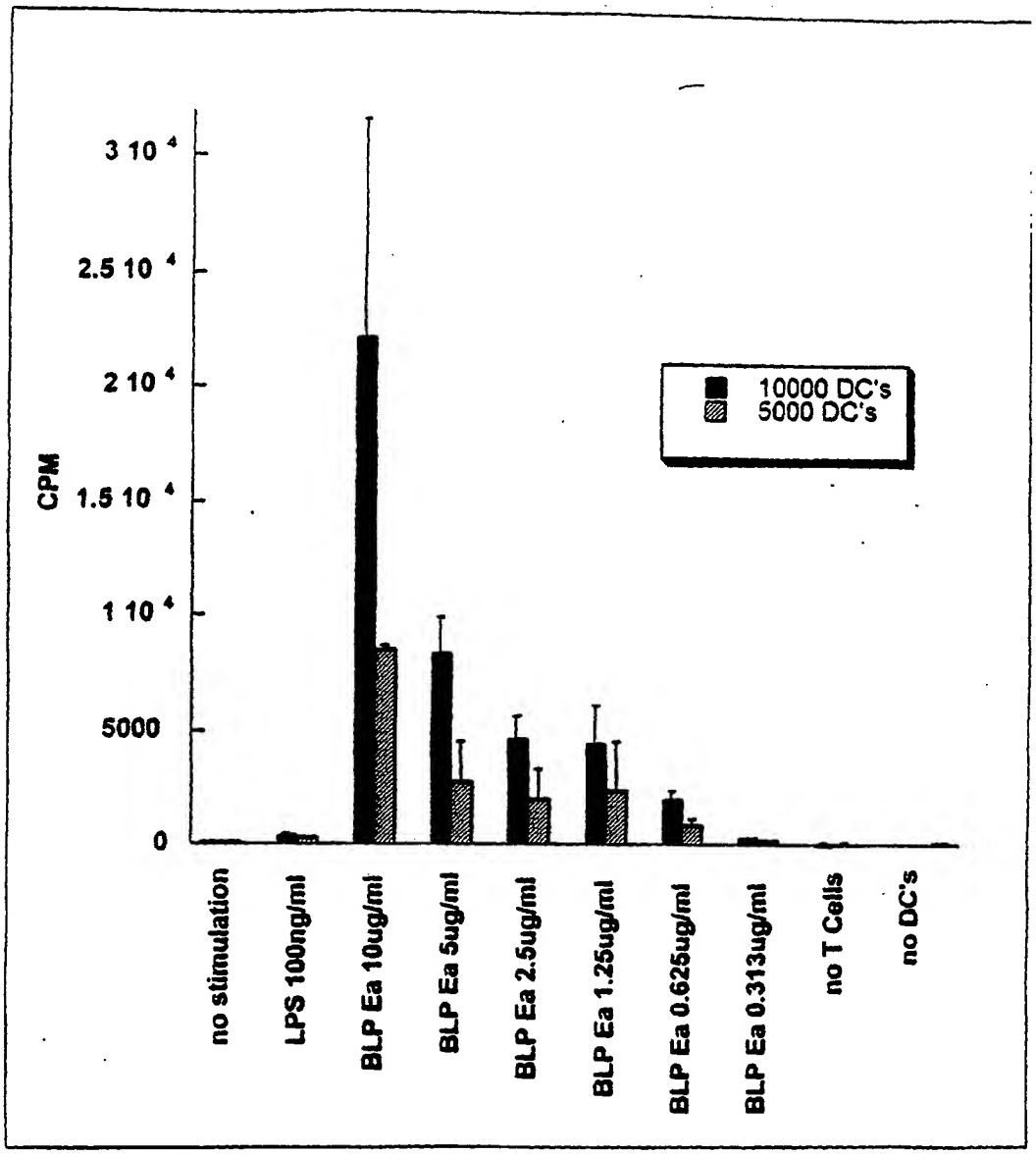
3 10 4
2.5 10 4
2 10 4
1.5 10 4
1 10 4
5000
0
CPM
10000 DC's
5000 DC's
no stimulation
LPS 100ng/ml
BLP Ea 10ug/ml
BLP Ea 5ug/ml
BLP Ea 2.5ug/ml
BLP Ea 1.25ug/ml
BLP Ea 0.625ug/ml
BLP Ea 0.313ug/ml
no T Cells
no DC's

Figure 7

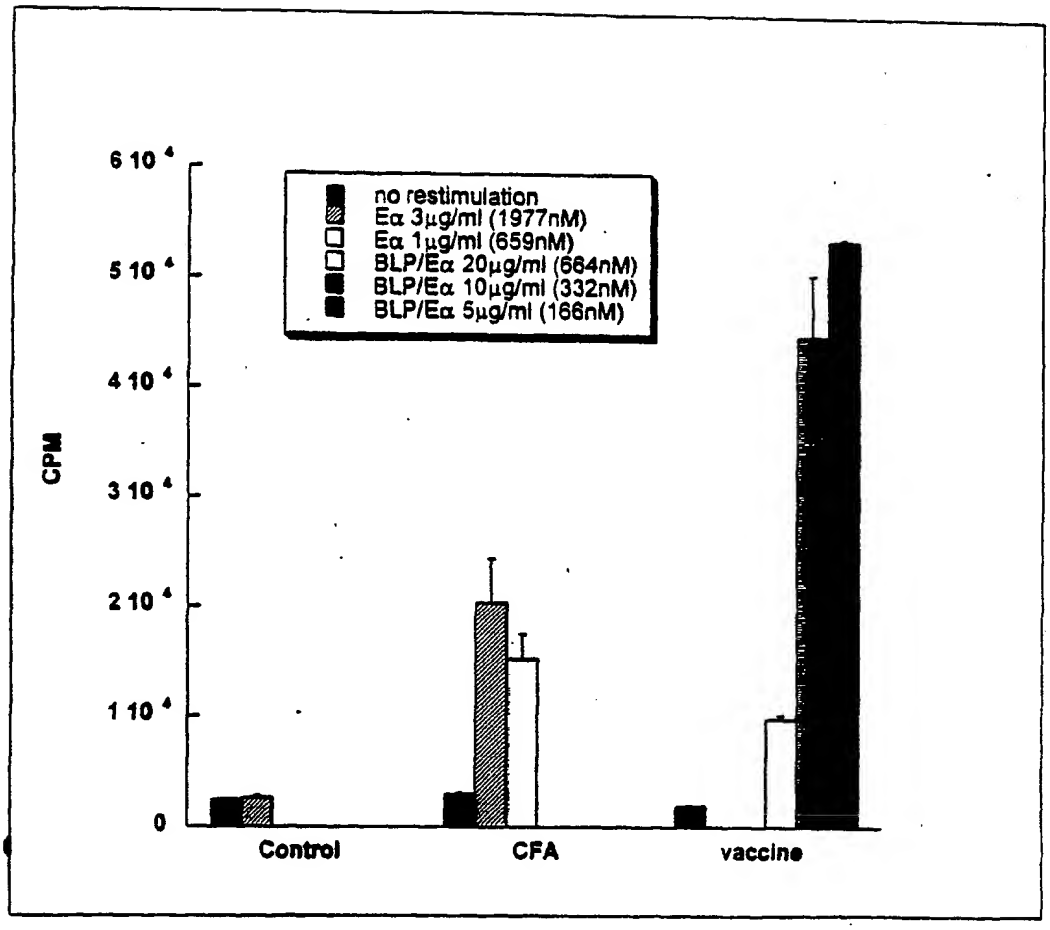
6 10 4
5 10 4
4 10 4
3 10 4
2 10 4
1 10 4
0
CPM
no restimulation
Eα 3µg/ml (1977nM)
Eα 1µg/ml (659nM)
BLP/Eα 20µg/ml (664nM)
BLP/Eα 10µg/ml (332nM)
BLP/Eα 5µg/ml (166nM)
Control
CFA
vaccine

Figure 8

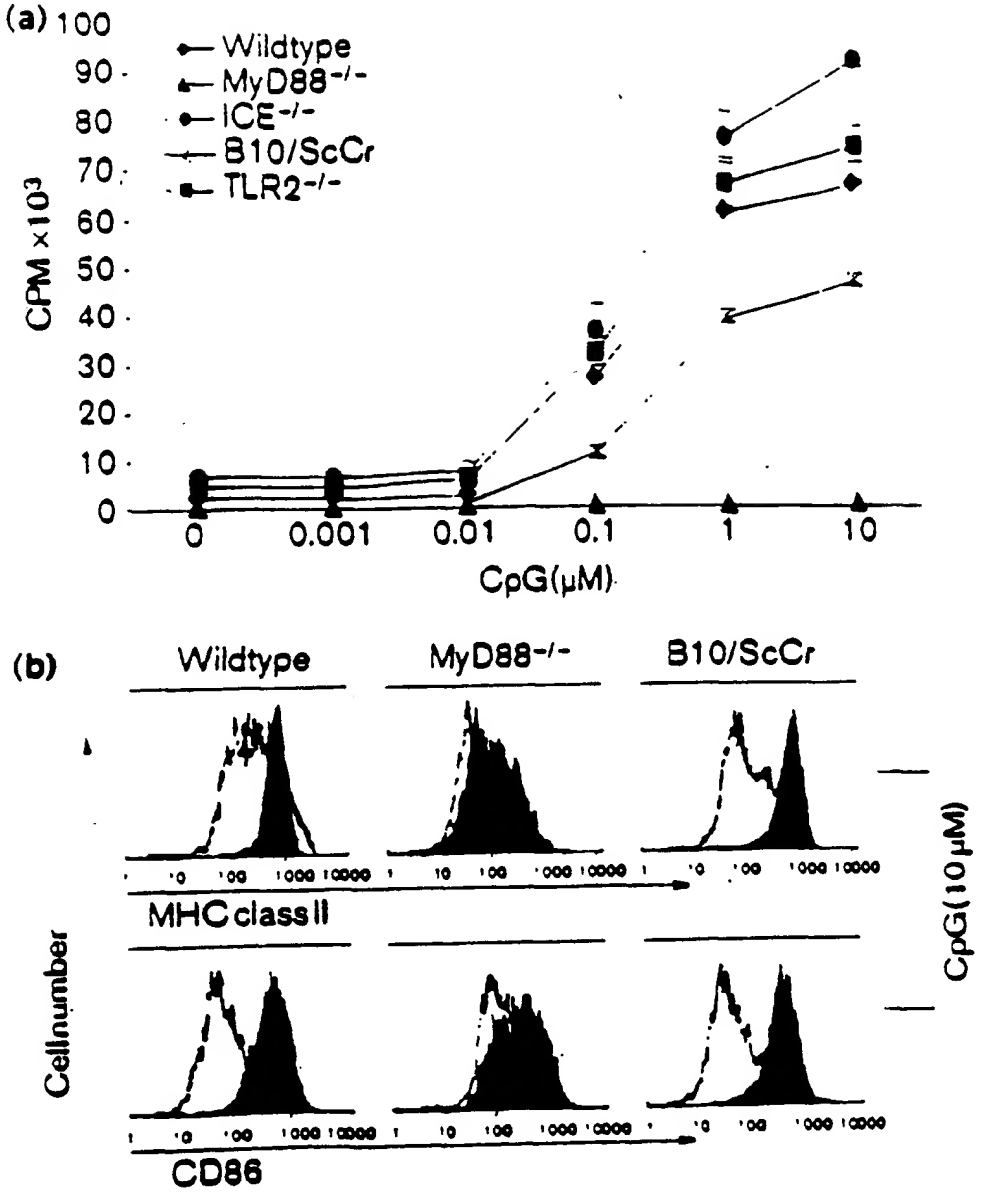
(a)
Wildtype
MyD88-/-
ICE-/-
B10/ScCr
TLR2-/-
CPM x10³
CpG(μM)
(b)
Wildtype
MyD88-/-
B10/ScCr
MHC class II
CD86
Cellnumber
CpG(10 μM)

Figure 9

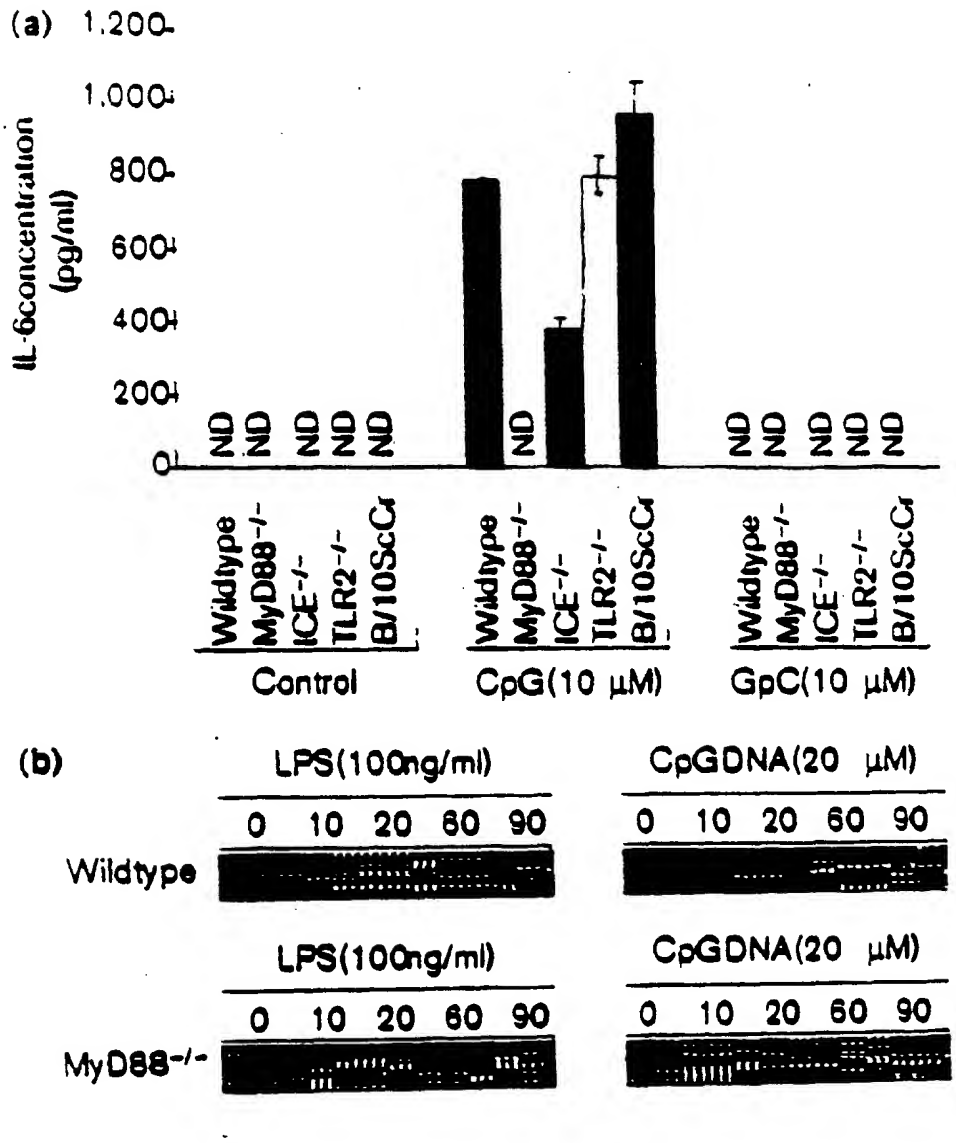
(a)
IL-6concentration (pg/ml)
1,200
1,000
800
600
400
200
0
ND
Wildtype
MyD88-/-
ICE-/-
TLR2-/-
B/10ScCr
Control
CpG(10 μM)
GpC(10 μM)
(b)
LPS(100ng/ml)
CpGDNA(20 μM)
0 10 20 60 90
Wildtype
MyD88-/-

Figure 10

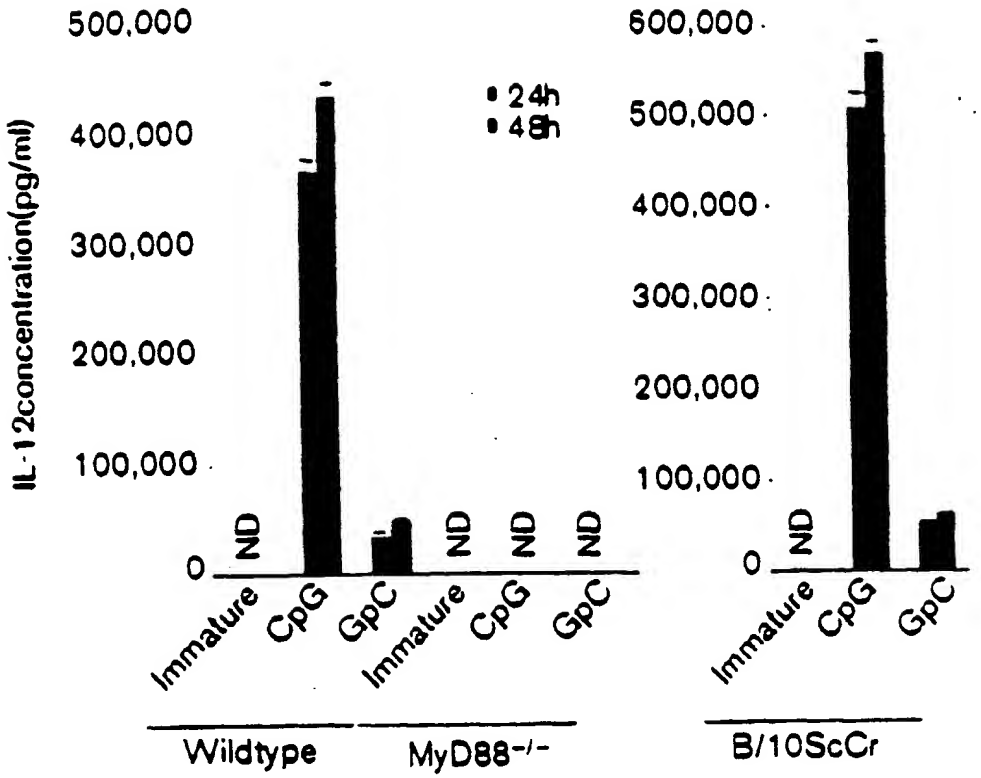
IL-12concentration(pg/ml)
500,000
400,000
300,000
200,000
100,000
0
600,000
500,000
400,000
300,000
200,000
100,000
0
24h
48h
ND
Immature
CpG
GpC
Wildtype
MyD88-/-
B/10ScCr

Figure 11

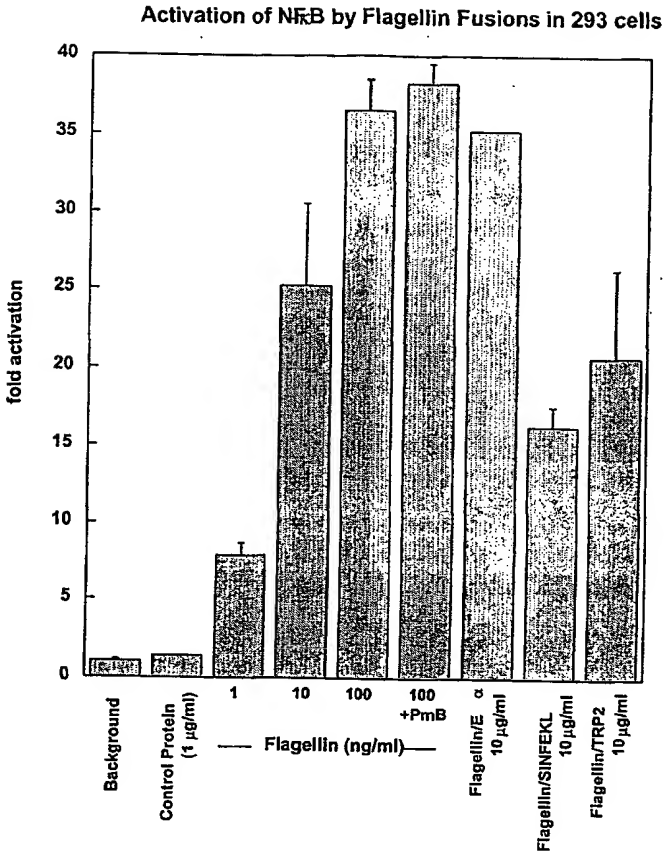
Activation of NFκB by Flagellin Fusions in 293 cells
fold activation
40
35
30
25
20
15
10
5
0
Background
Control Protein (1 µg/ml)
1
10
100
100 +PmB
Flagellin (ng/ml)
Flagellin/E α 10 µg/ml
Flagellin/SINFEKL 10 µg/ml
Flagellin/TRP2 10 µg/ml

Figure 12

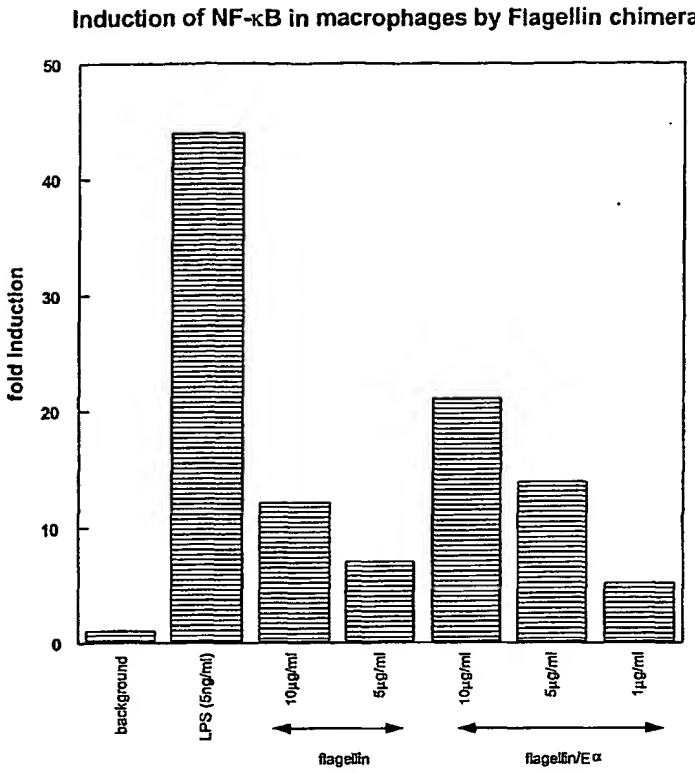
Induction of NF-κB in macrophages by Flagellin chimeras
fold induction
50
40
30
20
10
0
background
LPS (5ng/ml)
10µg/ml
5µg/ml
10µg/ml
5µg/ml
1µg/ml
flagellin
flagellin/Eα

Figure 13

NF-κB Activity in RAW κB cells in the presence of polymyxin B (0.5ug/ml)

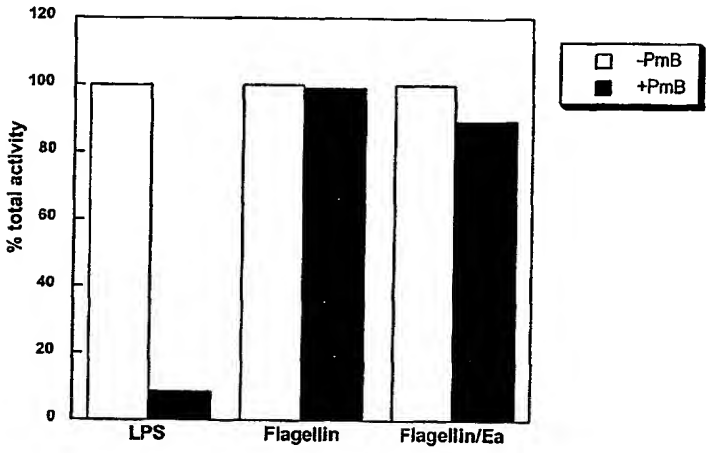

Figure 14

```
Met Lys Ala Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser Thr
1               5                  10                  15

Leu Leu Ala Gly
            20
```

Figure 15

```
Met Asn Arg Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser Thr
1               5                  10                  15

Leu Leu Ala Gly
      20
```

Figure 16

```
Met Asn Arg Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser His
1               5                  10                  15

Ser Ala Gly
```

Figure 17

```
Met Lys Ala Lys Ile Val Leu Gly Ala Val Ile Leu Ala Ser Gly Leu
1               5                  10                  15

Leu Ala Gly
```

Figure 18

Met Lys Lys Tyr Leu Leu Gly Ile Gly Leu Ile Leu Ala Leu Ile Ala

Figure 19

gcagcataat aagcagtatg gctggagcac tctgtaaatt aactcaatta gacagagcct
60
gatttaacaa ggaagactgg cgagaagctc ccctcattaa acctgatgtt agaggagctt
120
cggatgaaat taaatcagtg ttagttgttt gagtcacata aaattgcatg agcgtgtaca
180
catgtgcaca cgtgtaggct ctgtgattta ggtgggaatt ttgagaggag aggaaagggc
240
tagaactaaa cccaaagaaa aggaaagaag agaagaggaa aggaaagaaa aaagaaaagg
300
caatttgagt gagtaaaggt tccagaactc aggagtggaa gacaaggagt aaagtcagac
360
agaaaccagg tgggacgccg gccaggcctc ccaattaaga aggcatgggc cttgtgggat
420
gggggcttct gctgggttgt ctgggctgcg gaattctgct cagagctcgg gctcagtttc
480
cccgagtctg catgaccttg gatggcgtgc tgaacaagga atgctgcccg cctctgggtc
540
ccgaggcaac caacatctgt ggatttctag agggcagggg gcagtgcgca gaggtgcaaa
600
cagacaccag accctggagt ggcccttata tccttcgaaa ccaggatgac cgtgagcaat
660
ggccgagaaa attcttcaac cggacatgca aatgcacagg aaactttgct ggttataatt
720
gtggaggctg caagttcggc tggaccggcc ccgactgtaa tcggaagaag ccggccatcc
780
taagacggaa tatccattcc ctgactgccc aggagaggga gcagttcttg ggcgccttag
840
acctggccaa gaagagtatc catccagact acgtgatcac cacgcaacac tggctggggc
900
tgctcggacc caacgggacc cagccccaga tcgccaactg cagcgtgtat gacttttttg
960
tgtggctcca ttattattct gttcgagaca cattattagg tccaggacgc ccctataagg
1020
ccattgattt ctctcaccaa gggcctgcct ttgtcacgtg gcacaggtac catctgttgt
1080
ggctggaaag agaactccag agactcactg gcaatgagtc ctttgcgttg ccctactgga
1140
actttgcaac cgggaagaac gagtgtgacg tgtgcacaga cgactggctt ggagcagcaa
1200
gacaagatga cccaacgctg attagtcgga actcgagatt ctctacctgg gagattgtgt
1260
gcgacagctt ggatgactac aaccgccggg tcacactgtg taatggaacc tatgaaggtt
1320
tgctgagaag aaacaaagta ggcagaaata atgagaaact gccaacctta aaaaatgtgc
1380
aagattgcct gtctctccag aagtttgaca gccctccctt cttccagaac tctaccttca
1440

Figure 20

gcttcaggaa tgcactggaa gggtttgata aagcagacgg aacactggac tctcaagtca
1500
tgaaccttca taacttggct cactccttcc tgaatgggac caatgccttg ccacactcag
1560
cagccaacga ccctgtgttt gtggtcctcc actcttttac agacgccatc tttgatgagt
1620
ggctgaagag aaacaaccct tccacagatg cctggcctca ggaactggca cccattggtc
1680
acaaccgaat gtataacatg gtccccttct tcccaccggt gactaatgag gagctcttcc
1740
taaccgcaga gcaacttggc tacaattacg ccgttgatct gtcagaggaa gaagctccag
1800
tttggtccac aactctctca gtggtcattg gaatcctggg agctttcgtc ttgctcttgg
1860
ggttgctggc ttttcttcaa tacagaaggc ttcgcaaagg ctatgcgccc ttaatggaga
1920
caggtctcag cagcaagaga tacacggagg aagcctagca tgctcctacc tggcctgacc
1980
tgggtagtaa ctaattacac cgtcgctcat cttgagacag gtggaactct tcagcgtgtg
2040
ctctttagta gtgatgatga tgatgcctta gcaatgacaa ttatctctag ttgctgcttt
2100
gcttattgta cacagacaaa atgcttgggt cattcaccac ggtcaaagta aggtgtggct
2160
agtatatgtg acctttgatt ag
2182

Figure 20 (Continued)

```
Met Gly Leu Val Gly Trp Gly Leu Leu Leu Gly Cys Leu Gly Cys Gly
1               5                  10                  15

Ile Leu Leu Arg Ala Arg Ala Gln Phe Pro Arg Val Cys Met Thr Leu
            20                  25                  30

Asp Gly Val Leu Asn Lys Glu Cys Cys Pro Pro Leu Gly Pro Glu Ala
        35                  40                  45

Thr Asn Ile Cys Gly Phe Leu Glu Gly Arg Gly Gln Cys Ala Glu Val
    50                  55                  60

Gln Thr Asp Thr Arg Pro Trp Ser Gly Pro Tyr Ile Leu Arg Asn Gln
65                  70                  75                  80

Asp Asp Arg Glu Gln Trp Pro Arg Lys Phe Phe Asn Arg Thr Cys Lys
                85                  90                  95

Cys Thr Gly Asn Phe Ala Gly Tyr Asn Cys Gly Gly Cys Lys Phe Gly
            100                 105                 110

Trp Thr Gly Pro Asp Cys Asn Arg Lys Lys Pro Ala Ile Leu Arg Arg
        115                 120                 125

Asn Ile His Ser Leu Thr Ala Gln Glu Arg Glu Gln Phe Leu Gly Ala
    130                 135                 140

Leu Asp Leu Ala Lys Lys Ser Ile His Pro Asp Tyr Val Ile Thr Thr
145                 150                 155                 160

Gln His Trp Leu Gly Leu Leu Gly Pro Asn Gly Thr Gln Pro Gln Ile
                165                 170                 175

Ala Asn Cys Ser Val Tyr Asp Phe Phe Val Trp Leu His Tyr Tyr Ser
            180                 185                 190

Val Arg Asp Thr Leu Leu Gly Pro Gly Arg Pro Tyr Lys Ala Ile Asp
        195                 200                 205

Phe Ser His Gln Gly Pro Ala Phe Val Thr Trp His Arg Tyr His Leu
    210                 215                 220

Leu Trp Leu Glu Arg Glu Leu Gln Arg Leu Thr Gly Asn Glu Ser Phe
225                 230                 235                 240

Ala Leu Pro Tyr Trp Asn Phe Ala Thr Gly Lys Asn Glu Cys Asp Val
                245                 250                 255
```

Figure 21

```
Cys Thr Asp Asp Trp Leu Gly Ala Ala Arg Gln Asp Asp Pro Thr Leu
            260                 265                 270

Ile Ser Arg Asn Ser Arg Phe Ser Thr Trp Glu Ile Val Cys Asp Ser
        275                 280                 285

Leu Asp Asp Tyr Asn Arg Arg Val Thr Leu Cys Asn Gly Thr Thr Glu
    290                 295                 300

Gly Leu Leu Arg Arg Asn Lys Val Gly Arg Asn Asn Glu Lys Leu Pro
305                 310                 315                 320

Thr Leu Lys Asn Val Gln Asp Cys Leu Ser Leu Gln Lys Phe Asp Ser
                325                 330                 335

Pro Pro Phe Phe Gln Asn Ser Thr Phe Ser Phe Arg Asn Ala Leu Glu
            340                 345                 350

Gly Phe Asp Lys Ala Asp Gly Thr Leu Asp Ser Gln Val Met Asn Leu
        355                 360                 365

His Asn Leu Ala His Ser Phe Leu Asn Gly Thr Asn Ala Leu Pro His
    370                 375                 380

Ser Ala Ala Asn Asp Pro Val Phe Val Val Leu His Ser Phe Thr Asp
385                 390                 395                 400

Ala Ile Phe Asp Glu Trp Leu Lys Arg Asn Asn Pro Ser Thr Asp Ala
                405                 410                 415

Trp Pro Gln Glu Leu Ala Pro Ile Gly His Asn Arg Met Tyr Asn Met
            420                 425                 430

Val Pro Phe Phe Pro Pro Val Thr Asn Glu Glu Leu Phe Leu Thr Ala
        435                 440                 445

Glu Gln Leu Gly Tyr Asn Tyr Ala Val Asp Leu Ser Glu Glu Glu Ala
    450                 455                 460

Pro Val Trp Ser Thr Thr Leu Ser Val Val Ile Gly Ile Leu Gly Ala
465                 470                 475                 480

Phe Val Leu Leu Leu Gly Leu Leu Ala Phe Leu Gln Tyr Arg Arg Leu
                485                 490                 495

Arg Lys Gly Tyr Ala Pro Leu Met Glu Thr Gly Leu Ser Ser Lys Arg
            500                 505                 510

Tyr Thr Glu Glu Ala
    515
```

Figure 21 (Continued)

SEQUENCE LISTING

<110> YALE UNIVERSITY

<120> INNATE IMMUNE SYSTEM-DIRECTED VACCINES

<130> 044574-5071-WO
<140> NOT YET ASSIGNED

<141> 2001-07-31

<150> US 60/222,042
<151> 2000-07-31

<160> 13

<170> PatentIn version 3.0

<210> 1

<211> 4

<212> PRT

<213> Artificial

<220>

<223> lipidation site

<220>

<221> VARIANT

<222> (2)..(3)

<223> X=any amino acid, preferably serine

<400> 1

Cys Xaa Xaa Asn
1

<210> 2

<211> 78

<212> PRT

<213> Escherichia coli

<220>

<221> misc_feature

<223> BLP

<400> 2

Met Lys Ala Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser Thr
1 5 10 15

Leu Leu Ala Gly Cys Ser Ser Asn Ala Lys Ile Asp Gln Leu Ser Ser
20 25 30

Asp Val Gln Thr Leu Asn Ala Lys Val Asp Gln Leu Ser Asn Asp Val
35 40 45

Asn Ala Met Arg Ser Asp Val Gln Ala Ala Lys Asp Asp Ala Ala Arg
50 55 60

Ala Asn Gln Arg Leu Asp Asn Met Ala Thr Lys Tyr Arg Lys
65 70 75

<210> 3

<211> 20

<212> PRT

<213> Escherichia coli

<220>

<221> misc_feature

<223> BLP leader sequence

<400> 3

Met Lys Ala Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser Thr
1 5 10 15

Leu Leu Ala Gly
20

<210> 4

<211> 20

<212> PRT

<213> Erwinia amylovora

<220>

<221> misc_feature

<223> BLP leader sequence

<400> 4

Met Asn Arg Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser Thr
1 5 10 15

Leu Leu Ala Gly
20

<210> 5

<211> 19

<212> PRT

<213> Serratia marcescens

<220>

<221> misc_feature

<223> BLP leader sequence

<400> 5

Met Asn Arg Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser His
1 5 10 15

Ser Ala Gly

<210> 6

<211> 19

<212> PRT

<213> Proteus mirabilis

<220>

<221> misc_feature

<223> BLP leader sequence

<400> 6

Met Lys Ala Lys Ile Val Leu Gly Ala Val Ile Leu Ala Ser Gly Leu
1 5 10 15

Leu Ala Gly

<210> 7

<211> 16

<212> PRT

<213> Borrelia burgdorferi

<220>

<221> misc_feature

<223> Outer surface protein A

<400> 7

Met Lys Lys Tyr Leu Leu Gly Ile Gly Leu Ile Leu Ala Leu Ile Ala
1 5 10 15

<210> 8

<211> 20

<212> DNA

<213> Artificial

<220>

<223> CpG-DNA

<400> 8
tccatgacgt tcctgacgtt
20

<210> 9

<211> 73

<212> PRT

<213> Ambrosia trifida

<220>

<221> misc_feature

<223> Ra5G ragweed pollen allergen

<400> 9

Met Lys Asn Ile Phe Met Leu Thr Leu Phe Ile Leu Ile Ile Thr Ser
1 5 10 15

Thr Ile Lys Ala Ile Gly Ser Thr Asn Glu Val Asp Glu Ile Lys Gln
20 25 30

Glu Asp Asp Gly Leu Cys Tyr Glu Gly Thr Asn Cys Gly Lys Val Gly
35 40 45

Lys Tyr Cys Cys Ser Pro Ile Gly Lys Tyr Cys Val Cys Tyr Asp Ser
50 55 60

Lys Ala Ile Cys Asn Lys Asn Cys Thr
65 70

<210> 10

<211> 2182

<212> DNA

<213> Mus musculus

<220>

<221> misc_feature

<222> (405)..(1958)

<223> Tyrosinase-Related Kinase Protein 2 (TRP-2)

<220>

<221> misc_feature

<222> (945)..(968)

<223> T-cell epitope

<220>

<221> misc_recomb

<222> (840)..(1040)

<223> Region linked to BLP to form fusion protein

<400> 10
gcagcataat aagcagtatg gctggagcac tctgtaaatt aactcaatta gacagagcct
60

gatttaacaa ggaagactgg cgagaagctc ccctcattaa acctgatgtt agaggagctt
120

cggatgaaat taaatcagtg ttagttgttt gagtcacata aaattgcatg agcgtgtaca
180

catgtgcaca cgtgtaggct ctgtgattta ggtgggaatt ttgagaggag aggaaagggc
240

tagaactaaa cccaaagaaa aggaaagaag agaagaggaa aggaaagaaa aaagaaaagg
300

caatttgagt gagtaaaggt tccagaactc aggagtggaa gacaaggagt aaagtcagac
360

agaaaccagg tgggacgccg gccaggcctc ccaattaaga aggcatgggc cttgtgggat
420

gggggcttct gctgggttgt ctgggctgcg gaattctgct cagagctcgg gctcagtttc
480

cccgagtctg catgaccttg gatggcgtgc tgaacaagga atgctgcccg cctctgggtc
540

ccgaggcaac caacatctgt ggatttctag agggcagggg gcagtgcgca gaggtgcaaa
600

cagacaccag accctggagt ggcccttata tccttcgaaa ccaggatgac cgtgagcaat
660

ggccgagaaa attcttcaac cggacatgca aatgcacagg aaactttgct ggttataatt
720

gtggaggctg caagttcggc tggaccggcc ccgactgtaa tcggaagaag ccggccatcc
780

taagacggaa tatccattcc ctgactgccc aggagaggga gcagttcttg ggcgccttag
840

acctggccaa gaagagtatc catccagact acgtgatcac cacgcaacac tggctggggc
900

tgctcggacc caacgggacc cagccccaga tcgccaactg cagcgtgtat gacttttttg
960

tgtggctcca ttattattct gttcgagaca cattattagg tccaggacgc ccctataagg
1020

ccattgattt ctctcaccaa gggcctgcct ttgtcacgtg gcacaggtac catctgttgt
1080

ggctggaaag agaactccag agactcactg gcaatgagtc ctttgcgttg ccctactgga
1140

actttgcaac cgggaagaac gagtgtgacg tgtgcacaga cgactggctt ggagcagcaa
1200

gacaagatga cccaacgctg attagtcgga actcgagatt ctctacctgg gagattgtgt
1260

gcgacagctt ggatgactac aaccgccggg tcacactgtg taatggaacc tatgaaggtt
1320

tgctgagaag aaacaaagta ggcagaaata atgagaaact gccaaccttа aaaaatgtgc
1380

aagattgcct gtctctccag aagtttgaca gccctccctt cttccagaac tctaccttca
1440

gcttcaggaa tgcactggaa gggtttgata aagcagacgg aacactggac tctcaagtca
1500

tgaaccttca taacttggct cactccttcc tgaatgggac caatgccttg ccacactcag
1560

cagccaacga ccctgtgttt gtggtcctcc actcttttac agacgccatc tttgatgagt
1620

ggctgaagag aaacaaccct tccacagatg cctggcctca ggaactggca cccattggtc
1680

acaaccgaat gtataacatg gtccccttct tcccaccggt gactaatgag gagctcttcc
1740

taaccgcaga gcaacttggc tacaattacg ccgttgatct gtcagaggaa gaagctccag
1800

tttggtccac aactctctca gtggtcattg gaatcctggg agctttcgtc ttgctcttgg
1860

ggttgctggc ttttcttcaa tacagaaggc ttcgcaaagg ctatgcgccc ttaatggaga
1920

caggtctcag cagcaagaga tacacggagg aagcctagca tgctcctacc tggcctgacc
1980

tgggtagtaa ctaattacac cgtcgctcat cttgagacag gtggaactct tcagcgtgtg
2040

ctctttagta gtgatgatga tgatgcctta gcaatgacaa ttatctctag ttgctgcttt
2100

gcttattgta cacagacaaa atgcttgggt cattcaccac ggtcaaagta aggtgtggct
2160

agtatatgtg acctttgatt ag
2182

<210> 11

<211> 517

<212> PRT

<213> Mus musculus

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<221> misc_feature

<222> (181)..(188)

<223> T-cell epitope

<220>

<221> misc_recomb

<222> (146)..(212)

<223> Region linked to BLP to form fusion protein

<400> 11

Met Gly Leu Val Gly Trp Gly Leu Leu Leu Gly Cys Leu Gly Cys Gly
1 5 10 15

Ile Leu Leu Arg Ala Arg Ala Gln Phe Pro Arg Val Cys Met Thr Leu
20 25 30

Asp Gly Val Leu Asn Lys Glu Cys Cys Pro Pro Leu Gly Pro Glu Ala
35 40 45

Thr Asn Ile Cys Gly Phe Leu Glu Gly Arg Gly Gln Cys Ala Glu Val
50 55 60

Gln Thr Asp Thr Arg Pro Trp Ser Gly Pro Tyr Ile Leu Arg Asn Gln
65 70 75 80

Asp Asp Arg Glu Gln Trp Pro Arg Lys Phe Phe Asn Arg Thr Cys Lys
85 90 95

Cys Thr Gly Asn Phe Ala Gly Tyr Asn Cys Gly Gly Cys Lys Phe Gly
100 105 110

Trp Thr Gly Pro Asp Cys Asn Arg Lys Lys Pro Ala Ile Leu Arg Arg
115 120 125

Asn Ile His Ser Leu Thr Ala Gln Glu Arg Glu Gln Phe Leu Gly Ala
130 135 140

Leu Asp Leu Ala Lys Lys Ser Ile His Pro Asp Tyr Val Ile Thr Thr
145 150 155 160

```
Gln His Trp Leu Gly Leu Leu Gly Pro Asn Gly Thr Gln Pro Gln Ile
                165                 170                 175

Ala Asn Cys Ser Val Tyr Asp Phe Phe Val Trp Leu His Tyr Tyr Ser
            180                 185                 190

Val Arg Asp Thr Leu Leu Gly Pro Gly Arg Pro Tyr Lys Ala Ile Asp
        195                 200                 205

Phe Ser His Gln Gly Pro Ala Phe Val Thr Trp His Arg Tyr His Leu
    210                 215                 220

Leu Trp Leu Glu Arg Glu Leu Gln Arg Leu Thr Gly Asn Glu Ser Phe
225                 230                 235                 240

Ala Leu Pro Tyr Trp Asn Phe Ala Thr Gly Lys Asn Glu Cys Asp Val
                245                 250                 255

Cys Thr Asp Asp Trp Leu Gly Ala Ala Arg Gln Asp Asp Pro Thr Leu
            260                 265                 270

Ile Ser Arg Asn Ser Arg Phe Ser Thr Trp Glu Ile Val Cys Asp Ser
        275                 280                 285

Leu Asp Asp Tyr Asn Arg Arg Val Thr Leu Cys Asn Gly Thr Thr Glu
    290                 295                 300

Gly Leu Leu Arg Arg Asn Lys Val Gly Arg Asn Asn Glu Lys Leu Pro
305                 310                 315                 320

Thr Leu Lys Asn Val Gln Asp Cys Leu Ser Leu Gln Lys Phe Asp Ser
                325                 330                 335

Pro Pro Phe Phe Gln Asn Ser Thr Phe Ser Phe Arg Asn Ala Leu Glu
            340                 345                 350

Gly Phe Asp Lys Ala Asp Gly Thr Leu Asp Ser Gln Val Met Asn Leu
        355                 360                 365

His Asn Leu Ala His Ser Phe Leu Asn Gly Thr Asn Ala Leu Pro His
    370                 375                 380

Ser Ala Ala Asn Asp Pro Val Phe Val Val Leu His Ser Phe Thr Asp
385                 390                 395                 400

Ala Ile Phe Asp Glu Trp Leu Lys Arg Asn Asn Pro Ser Thr Asp Ala
                405                 410                 415

Trp Pro Gln Glu Leu Ala Pro Ile Gly His Asn Arg Met Tyr Asn Met
            420                 425                 430

Val Pro Phe Phe Pro Pro Val Thr Asn Glu Glu Leu Phe Leu Thr Ala
        435                 440                 445

Glu Gln Leu Gly Tyr Asn Tyr Ala Val Asp Leu Ser Glu Glu Glu Ala
    450                 455                 460

Pro Val Trp Ser Thr Thr Leu Ser Val Val Ile Gly Ile Leu Gly Ala
465                 470                 475                 480
```

Phe Val Leu Leu Leu Gly Leu Leu Ala Phe Leu Gln Tyr Arg Arg Leu
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Tyr Thr Glu Glu Ala
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Ala Asn Cys Ser Val Tyr Asp Phe Phe Val Trp Leu His Tyr Tyr Ser
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Phe Ser His Gln
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<223> T-cell epitope

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Val Tyr Asp Phe Phe Val Trp Leu
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/24228

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :A61K 39/00, 39/02; C12P 21/00, 1/21

US CL : 424/184.1, 190.1, 192.1; 435/69.1, 252.3; 536/23.5

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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, MEDLINE, BIOSIS, EMBASE, SCISERACH, CAPLUS ON STN

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,601,831 A (GREEN et al) 11 February 1997 (2/11/1997), see entire document.	1-11, 16-18, 22-26, 29-31, 37-40, 43-44, 50-52, 56-58 64-69, 80 and 82-84
X	EP 0,540,128 A1 (BIOTECHNOLOGY AUSTRALIA PTY. LTD.) 05 May 1993 (05/05/93), see entire document, page 20, lines 26-48, in particular.	1-12, 16-18, 22-31, 37-40, 50 64-72, 76-78, 80 and 82-84

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

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PCT/US01/24228

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97/06590 A1 (BIOENTERPRISES PTY. LTD.) 05 November 1987 (05.11.1987), see entire document, page 16, see claims 1-35, claims 38-42, in particular.	1-12, 16-18, 22-31, 37-40, 50, 55, 59-61, 64-72, 75-78 and 82-84
Y	NAKAMURA, K et al. DNA Sequence of the Gene for the Outer Membrane Lipoprotein of E. Coli an Extremely AT-Rich Promoter. Cell. December 1979, Vol. 18, pages 1109-1117, see page 1114, in particular.	13, 19-21 and 62
Y	MEEKER A et al. A Fusion Protein Between Serum Amyloid A and Staphylococcal Nuclease - Synthesis, Purification, and Structural Studies. Proteins. March 1998, Vol. 30 No. 4, pages 381-7, see entire document.	14, 34, 41-42, 49, 73 and 79
Y	VERMA, N et al. Delivery of class I and class II MHC-restricted T-cell epitopes of listeriolysin of Listeria monocytogenes by attenuated salmonella. Vaccine. 1995, Vol. 13, No. 2, pages 142-150, see entire document.	14-15, 34-36, 41-42, 49, 63 and 73
Y	US 5,693,495 A (BREITENEDER et al) 02 December 1997 (2.12.1997), see entire document.	32
Y	US 5,877,289 A (THORPE et al) 02 March 1999 (2.3.1999), see entire document.	33, 45-49, 53-54 and 73-74

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(71) Applicant *(for all designated States except US)*: **YALE UNIVERSITY** [US/US]; 451 College Street, New Haven, CT 06510 (US).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **MEDZHITOV, Ruslan, M. PH., D.** [US/US]; 310 Cedar Street, New Haven, CT 06520-08011 (US).

(74) Agent: **HALLIDAY, Christopher, I.**; Morgan, Lewis & Bockius LLP, 1701 Market Street, Philadelphia, PA 19103 (US).

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(54) Title: INNATE IMMUNE SYSTEM-DIRECTED VACCINES

(57) Abstract: The present invention provides novel vaccines, method for the production of such vaccines and methods of using such vaccines. The novel vaccines of the present invention combine both of the signals necessary to activate native T-cells - specific antigen and the co-stimulatory signal - leading to a robust and specific T-cell immune response.

INNATE IMMUNE SYSTEM-DIRECTED VACCINES

FIELD OF THE INVENTION

The present invention relates to novel vaccines, the production of such vaccines and methods of using such vaccines. More specifically, this invention provides unique vaccine molecules comprising an isolated Pathogen Associated Molecular Pattern (PAMP) and an antigen. Even more specifically, this invention provides novel fusion proteins comprising an isolated PAMP and an antigen such that vaccination with these fusion proteins provides the two signals required for native T-cell activation. The novel vaccines of the present invention provide an efficient way of making and using a single molecule to induce a robust T-cell immune response that activates other aspects of the adaptive immune responses. The methods and compositions of the present invention provide a powerful way of designing, producing and using vaccines targeted to specific antigens, including antigens associated with selected pathogens, tumors, allergens and other disease-related molecules.

BACKGROUND OF THE INVENTION

All articles, patents and other materials referred to below are specifically incorporated herein by reference.

1. Immunity

Multicellular organisms have developed two general systems of immunity to infectious agents. The two systems are innate or natural immunity (also known as "innate immunity") and adaptive (acquired) or specific immunity. The major difference between the two systems is the mechanism by which they recognize infectious agents.

The innate immune system uses a set of germline-encoded receptors for the recognition of conserved molecular patterns present in microorganisms. These molecular patterns occur in certain constituents of microorganisms including: lipopolysaccharides, peptidoglycans, lipoteichoic acids, phosphatidyl cholines, bacteria-specific proteins, including lipoproteins, bacterial DNAs, viral single and double-stranded RNAs, unmethylated CpG-DNAs, mannans and a variety of other bacterial and fungal cell wall components. Such molecular patterns can also occur in other molecules such as plant alkaloids. These targets of innate immune recognition are called Pathogen Associated Molecular Patterns (PAMPs) since they are produced by microorganisms and not by the infected host organism. (Janeway *et al.* (1989) *Cold Spring Harb. Symp. Quant. Biol.* 54: 1-13; Medzhitov *et al.* (1997) *Curr. Opin. Immunol.* 94: 4-9).

The receptors of the innate immune system that recognize PAMPs are called Pattern Recognition Receptors (PRRs). (Janeway *et al.* (1989) *Cold Spring Harb. Symp. Quant. Biol.* 54: 1-13; Medzhitov *et al.* (1997) *Curr. Opin. Immunol.* 94: 4-9). These receptors vary in structure and belong to several different protein families. Some of these receptors recognize PAMPs directly (*e.g.*, CD14, DEC205, collectins), while others (*e.g.*, complement receptors) recognize the products generated by PAMP recognition. Members of these receptor families can, generally, be divided into three types: 1) humoral receptors circulating in the plasma; 2) endocytic receptors expressed on immune-cell surfaces, and 3) signaling receptors that can be expressed either on the cell surface or intracellularly. (Medzhitov *et al.* (1997) *Curr. Opin. Immunol.* 94: 4-9; Fearon *et al.* (1996) *Science* 272: 50-3).

Cellular PRRs are expressed on effector cells of the innate immune system, including cells that function as professional antigen-presenting cells (APC) in adaptive immunity. Such effector cells include, but are not limited to, macrophages, dendritic cells, B lymphocytes and surface epithelia. This expression profile allows PRRs to directly induce innate effector mechanisms, and also to alert the host organism to the presence of infectious agents by inducing the expression of a set of endogenous signals, such as inflammatory cytokines and chemokines, as discussed below. This latter function allows efficient mobilization of effector forces to combat the invaders.

In contrast, the adaptive immune system, which is found only in vertebrates, uses two types of antigen receptors that are generated by somatic mechanisms during the development of each individual organism. The two types of antigen receptors are the T-cell receptor (TCR) and the immunoglobulin receptor (IgR), which are expressed on two specialized cell types, T-lymphocytes and B-lymphocytes, respectively. The specificities of these antigen receptors are generated at random during the maturation of lymphocytes by the processes of somatic gene rearrangement, random pairing of receptor subunits, and by a template-independent addition of nucleotides to the coding regions during the rearrangement.

Recent studies have demonstrated that the innate immune system plays a crucial role in the control of initiation of the adaptive immune response and in the induction of appropriate cell effector responses. (Fearon *et al.* (1996) *Science* 272: 50-3; Medzhitov *et al.* (1997) *Cell* 91: 295-8). Indeed, it is now well established that the activation of naive T-lymphocytes requires two distinct signals: one is a specific

antigenic peptide recognized by the TCR, and the other is the so called co-stimulatory signal, B7, which is expressed on APCs and recognized by the CD28 molecule expressed on T-cells. (Lenschow *et al.* (1996) *Annu. Rev. Immunol.* 14: 233-58). Activation of naive $CD4^+$ T-lymphocytes requires that both signals, the specific antigen and the B7 molecule, are expressed on the same APC. If a naive CD4 T-cell recognizes the antigen in the absence of the B7 signal, the T-cell will die by apoptosis. Expression of B7 molecules on APCs, therefore, controls whether or not the naive CD4 T-lymphocytes will be activated. Since CD4 T-cells control the activation of CD8 T-cells for cytotoxic functions, and the activation of B-cells for antibody production, the expression of B7 molecules determines whether or not an adaptive immune response will be activated.

Recent studies have also demonstrated that the innate immune system plays a crucial role in the control of B7 expression. (Fearon *et al.* (1996) *Science* 272: 50-3; Medzhitov *et al.* (1997) *Cell* 91: 295-8). As mentioned earlier, innate immune recognition is mediated by PRRs that recognize PAMPs. Recognition of PAMPs by PRRs results in the activation of signaling pathways that control the expression of a variety of inducible immune response genes, including the genes that encode signals necessary for the activation of lymphocytes, such as B7, cytokines and chemokines. (Medzhitov *et al.* (1997) *Cell* 91: 295-8; Medzhitov *et al.* (1997) *Nature* 388: 394-397). Induction of B7 expression by PRR upon recognition of PAMPs thus accounts for self/nonself discrimination and ensures that only T-cells specific for microorganism-derived antigens are normally activated. This mechanism normally prevents activation of autoreactive lymphocytes specific for self-antigens.

Receptors of the innate immune system that control the expression of B7 molecules and cytokines have recently been identified. (Medzhitov *et al.* (1997) *Nature* 388: 394-397; Rock *et al.* (1998) *Proc. Natl. Acad. Sci. USA*, 95: 588-93). These receptors belong to the family of Toll-like receptors (TLRs), so called because they are homologous to the *Drosophila* Toll protein which is involved both in dorsoventral patterning in *Drosophila* embryos and in the immune response in adult flies. (Lemaitre *et al.* (1996) *Cell* 86: 973-83). In mammalian organisms, such TLRs have been shown to recognize PAMPs such as the bacterial products LPS, peptidoglycan, and lipoprotein. (Schwandner *et al. (1999) J. Biol. Chem.* 274: 17406-9; Yoshimura *et al.* (1999) J. *Immunol.* 163: 1-5; Aliprantis *et al.* (1999) *Science* 285: 736-9).

2. Vaccine Development

Vaccines have traditionally been used as a means to protect against disease caused by infectious agents. However, with the advancement of vaccine technology, vaccines have been used in additional applications that include, but are not limited to, control of mammalian fertility, modulation of hormone action, and prevention or treatment of tumors.

The primary purpose of vaccines used to protect against a disease is to induce immunological memory to a particular microorganism. More generally, vaccines are needed to induce an immune response to specific antigens, whether they belong to a microorganism or are expressed by tumor cells or other diseased or abnormal cells. Division and differentiation of B- and T-lymphocytes that have surface receptors specific for the antigen generate both specificity and memory.

In order for a vaccine to induce a protective immune response, it must fulfill the following requirements: 1) it must include the specific antigen(s) or fragment(s) thereof that will be the target of protective immunity following vaccination; 2) it must present such antigens in a form that can be recognized by the immune system, *e.g.*, a form resistant to degradation prior to immune recognition; and 3) it must activate APCs to present the antigen to $CD4^+$ T-cells, which in turn induce B-cell differentiation and other immune effector functions.

Conventional vaccines contain suspensions of attenuated or killed microorganisms, such as viruses or bacteria, incapable of inducing severe infection by themselves, but capable of counteracting the unmodified (or virulent) species when inoculated into a host. Usage of the term has now been extended to include essentially any preparation intended for active immunologic prophylaxis (*e.g.*, preparations of killed microbes of virulent strains or living microbes of attenuated (variant or mutant) strains; microbial, fungal, plant, protozoan, or metazoan derivatives or products; synthetic vaccines). Examples of vaccines include, but are not limited to, cowpox virus for inoculating against smallpox, tetanus toxoid to prevent tetanus, whole-inactivated bacteria to prevent whooping cough (pertussis), polysaccharide subunits to prevent streptococcal pneumonia, and recombinant proteins to prevent hepatitis B.

Although attenuated vaccines are usually immunogenic, their use has been limited because their efficacy generally requires specific, detailed knowledge of the molecular determinants of virulence. Moreover, the use of attenuated pathogens in

vaccines is associated with a variety of risk factors that in most cases prevent their safe use in humans.

The problem with synthetic vaccines, on the other hand, is that they are often non-immunogenic or non-protective. The use of available adjuvants to increase the immunogenicity of synthetic vaccines is often not an option because of unacceptable side effects induced by the adjuvants themselves.

An adjuvant is defined as any substance that increases the immunogenicity of admixed antigens. Although chemicals such as alum are often considered to be adjuvants, they are in effect akin to carriers and are likely to act by stabilizing antigens and/or promoting their interaction with antigen-presenting cells. The best adjuvants are those that mimic the ability of microorganisms to activate the innate immune system. Pure antigens do not induce an immune response because they fail to induce the costimulatory signal (*e.g.*, B7.1 or B7.2) necessary for activation of lymphocytes. Thus, a key mechanism of adjuvant activity has been attributed to the induction of costimulatory signals by microbial, or microbial-like, constituents carrying PAMPs that are routine constituents of adjuvants. (Janeway *et al.* (1989) *Cold Spring Harb. Symp. Quant. Biol.*, 54: 1-13). As discussed above, the recognition of these PAMPs by PRRs induces the signals necessary for lymphocyte activation (such as B7) and differentiation (effector cytokines).

Because adjuvants are often used in molar excess of antigens and thus trigger an innate immune response in many cells that do not come in contact with the target antigen, this non-specific induction of the innate immune system to produce the signals that are required for activation of an adaptive immune response produces an

excessive inflammatory response that renders many of the most potent adjuvants clinically unsuitable. Alum is currently approved for use as a clinical adjuvant, even though it has relatively limited efficacy, because it is not an innate immune stimulant and thus does not cause excessive inflammation. However, a vaccine that included the use of an innate immune stimulant in such a way as not to elicit excess inflammation could be far more effective than vaccines comprising an antigen together with an adjuvant such as alum. Fusion of an antigen with a PAMP, such as bacterial lipoprotein (BLP), optimizes the stoichiometry of the two signals and coordinates their effect on the same APC, thus minimizing the unwanted excessive inflammatory responses that occur when antigens are mixed with adjuvants comprising innate immune stimulants to increase their immunogenicity. In addition, the chimeric constructs of the present invention will prevent activation of APCs that do not take up the antigen. Activation of such APCs in the absence of uptake and presentation of the target antigen can lead to the induction of autoimmune responses, which, again, is one of the problems with commonly used innate immunity-stimulating adjuvants that prevents or limits their use in humans. Notably, the chimeric constructs of the present invention exhibit the essential immunological characteristics or properties expected of a conventional vaccine supplemented with an adjuvant, but the chimeric constructs do not induce an excessive inflammatory reaction as is often induced by an adjuvant. Thus, the vaccine approach described in the present invention minimizes or eliminates undesired side effects (*e.g.*, excessive inflammatory reaction, autoimmunity) yet induces a very potent and specific immune

response, and provides a favorable alternative to vaccines comprising mixtures of antigens and adjuvants.

3. Alternative Vaccine Strategies

Immune Stimulating Complexes for Use as Vaccines. Immune stimulating complexes (ISCOMS) are cage-like structures comprising Quil-A, cholesterol, adjuvant active saponin and phospholipids that induce a wide range of systemic immune responses. (Mowat *et al.* (1999) *Immunol. Lett.* 65: 133-140; Smith *et al.*, (1999) *J. Immunol.* 162(9): 5536-5546). ISCOMS are suitable for repeated administration of different antigens to an individual because these complexes allow the entry of antigen into both MHC I and II processing pathways. (Mowat *et al.* (1991) *Immunol.* 72: 317-322).

ISCOMS have been used with conjugates of modified soluble proteins. (Reid (1992) *Vaccine* 10(9): 597-602). These complexes also produce a Th1 type response, as would be expected for such a vaccine. (Morein *et al.* (1999) *Methods* 19: 94-102).

However, in contrast to the molecules of the present invention, ISCOMS are far more complex structures that present potential problems of reproducibility and dosing; nor do they contain conjugates between an antigen and a PAMP. Since ISCOMS do not specifically target APCs their use can result in problems of toxicity and a lack of specificity.

Multiple Antigenic Recombinant Vaccines. Various U.S. patents disclose chimeric proteins consisting of multiple antigenic peptides (MAPs) for use as vaccines. For example, Klein *et al.* were granted a family of patents (*e.g.*, U.S. Patent

No. 6,033,668; 6,017,539; 5,998,169; and 5,968,776) which describe genes encoding multimeric hybrids comprising an immunogenic region of a protein from a first antigen linked to an immunogenic region from a second pathogen. While the patents are focused on human Parainfluenza/Respiratory syncytial virus protein chimeras, the first and second antigens may be more broadly selected from bacterial and viral pathogens. Although the vaccines contemplated by Klein et al. are fusion proteins, all the component peptides are all selected by virtue of their being antigens (i.e., being recognized by a TCR or IgR) rather than a pairing of antigens with PAMPs, and thus the vaccines are not designed to stimulate the innate immune system.

Sinugalia (U.S. Patent No. 5,114,713) discloses vaccines consisting of peptides from the circumsporozoite protein of *Plasmodium falciparum* (*P. falciparum*) as universal T-cell epitopes that can be coupled to B-cell epitopes, such as surface proteins derived from pathogenic agents *(e.g.,* bacteria, viruses, fungi or parasites). These combined peptides can be prepared by recombinant means. These universal T-cell epitopes are not known to be PAMPs, and they act via the adaptive immune system rather than the innate immune system.

Russell-Jones *et al.* (U.S. Patent No. 5,928,644) disclose T-cell epitopes derived from the TraT protein of *E. coli* that is used to produce hybrid molecules to raise immune responses against various targets to include parasites, soluble factors (*e.g.*, LSH) and viruses. Thus, these constructs provide strategies for increasing the complexity of the antigenic nature of the vaccines, thereby promoting strengthened or multiple adaptive immune responses. However, the epitopes are not known to be

PAMPs, and they act via the adaptive immune system rather than the innate immune system.

Thus, the aforementioned inventions are very different in intent, concept, strategy and mode of action from the present invention.

4. Overview of the Novel Vaccines of the Present Invention

The novel vaccines of the present invention comprise one or more isolated PAMPs in combination with one or more antigens. The antigens used in the vaccines of the present invention can be any type of antigen (*e.g.*, including but not limited to pathogen-related antigens, tumor-related antigens, allergy-related antigens, neural defect-related antigens, cardiovascular disease antigens, rheumatoid arthritis-related antigens, other disease-related antigens, hormones, pregnancy-related antigens, embryonic antigens and/or fetal antigens and the like). Examples of various types of vaccines, which can be produced by the present invention, are provided in Figure 1.

In one preferred embodiment, the vaccines are recombinant proteins, or recombinant lipoproteins, or recombinant glycoproteins, which contain a PAMP (*e.g.*, BLP or Flagellin) and one or more antigens. The basic concept for preparing a fusion protein of the present invention is provided in Figure 1.

Upon administration into human or animal subjects, the vaccines of the present invention will interact with APCs, such as dendritic cells and macrophages. This interaction will have two consequences: First, the PAMP portion of the vaccine will interact with a PRR such as a TLR and stimulate a signaling pathway, such as the NF-κB, JNK and/or p38 pathways. Second, due to the PAMP's interaction with TLRs and/or other pattern-recognition receptors, the recombinant vaccine will be

taken up into dendritic cells and macrophages by phagocytosis, endocytosis, or macropinocytosis, depending on the cell type, the size of the recombinant vaccine, and the identity of the PAMP.

Activation of TLR-induced signaling pathways will lead to the induction of the expression of cytokines, chemokines, adhesion molecules, and co-stimulatory molecules by dendritic cells and macrophages and, in some cases, B-cells. Uptake of the vaccines will lead to the processing of the antigen(s) fused to the PAMP and their presentation by the MHC class-I and MHC class-II molecules. This will generate the two signals required for the activation of naive T-cells – a specific antigen signal and the co-stimulatory signal. In addition, chemokines induced by the vaccine (due to PAMP interaction with TLR) will recruit naive T-cells to the APC and cytokines, like IL-12, which will induce T-cell differentiation into Th-1 effector cells. As a result, a robust T-cell immune response will be induced, which will in turn activate other aspects of the adaptive immune responses, such as activation of antigen-specific B-cells and macrophages.

Thus, the novel vaccines of the present invention provide an efficient way to produce an immune response to one or more specific antigens without the adverse side effects normally associated with conventional vaccines.

SUMMARY OF THE INVENTION

The present invention relates generally to vaccines, methods of making vaccines and methods of using vaccines.

More specifically, the present invention provides vaccines comprising an isolated PAMP, immunostimulatory portion or immunostimulatory derivative thereof

and an antigen or an immunogenic portion or immunogenic derivative thereof. An example of a preferred vaccine of the present invention is a fusion protein comprising a PAMP, immunostimulatory portion or immunostimulatory derivative thereof and an antigen or an immunogenic portion or immunogenic derivative thereof.

The vaccines of the present invention can comprise any PAMP peptide or protein, including, but not limited to, the following PAMPs: peptidoglycans, lipoproteins and lipopeptides, Flagellins, outer membrane proteins (OMPs), outer surface proteins (OSPs), other protein components of the bacterial cell walls, and other PRR ligands.

One preferred PAMP of the present invention is BLP, including the BLP encoded by the polypeptide of SEQ ID NO: 2, set forth in Figure 15. In addition to protein PAMPs, also useful in the vaccines of the present invention are peptide mimetics of any non-protein PAMP.

Antigens useful in the present invention include, but are not limited to, those that are microorganism-related, and other disease-related antigens, including but not limited to those that are allergen-related and cancer-related. The antigen component of the vaccine can be derived from sources that include, but are not limited to, bacteria, viruses, fungi, yeast, protozoa, metazoa, tumors, malignant cells, plants, animals, humans, allergens, hormones and amyloid-β peptide. The antigens, immunogenic portions or immunogenic derivatives thereof can be composed of peptides, polypeptides, lipoproteins, glycoproteins, mucoproteins and the like.

The various vaccines of the present invention include, but are not limited to:

1) one or more PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, conjugated to one or more antigens, immunogenic portions or immunogenic derivatives thereof;

2) a PAMP/antigen fusion protein comprising one or more PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, and one or more antigens, immunogenic portions or immunogenic derivatives thereof; and

3) a modified antigen, immunogenic portion or immunogenic derivative thereof, that comprises a leader sequence fused to a lipidation or glycosylation consensus sequence that is further fused to the antigen, or an immunogenic portion or immunogenic derivative thereof.

The present invention also encompasses such vaccines further comprising a pharmaceutically acceptable carrier, including, but not limited to, alum.

More specifically, the present invention provides fusion proteins comprising one or more PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, and one or more antigens, immunogenic portions or immunogenic derivatives thereof. The PAMP domains of the fusion proteins of the present invention can be composed of amino acids, amino acid polymers, peptidoglycans, glycoproteins, and lipoproteins or any other suitable component. One preferred PAMP to use in the fusion proteins of the present invention is BLP, including the BLP encoded by the polypeptide of SEQ ID NO: 2. Flagellin is another PAMP to use in the fusion proteins of the present invention, and is provided by (but not limited to) accession numbers P04949 (E. Coli Flagellin) and A24262 (Salmonella Flagellin). Useful antigen domain(s) in the fusion proteins of the present invention include, but are not

limited to, Eα (a peptide antigen derived from mouse MHC class-II I-E), listeriolysin, PSMA, HIV gp120, Ra5G and TRP-2. In one preferred embodiment, the fusion proteins of the present invention include a construct comprising the following components: a leader peptide that signals lipidation or glycosylation of the consensus sequence, a lipidation and/or glycosylation consensus sequence, and antigen. More specifically, the fusion proteins of the present invention include a construct comprising a leader sequence—CXXN—antigen, wherein the leader peptide is a signal for lipidation of the consensus sequence and wherein X is any amino acid, preferably serine. Examples of leader peptides useful in the present invention include, but are not limited to, those selected from the peptides of SEQ ID NO: 3 (shown in Figure 15), SEQ ID NO: 4 (shown in Figure 16), SEQ ID NO: 5 (shown in Figure 17), SEQ ID NO: 6 (shown in Figure 18) and SEQ ID NO: 7 (shown in Figure 19).

In another embodiment, the present invention provides also provides a fusion protein comprising an isolated PAMP and an antigen, wherein the antigen is a self-antigen.

The present invention further provides methods of recombinantly producing the fusion proteins of the present invention. Thus, the present invention provides recombinant expression vectors comprising a nucleotide sequence encoding the chimeric constructs of the present invention as well as host cells transformed with such recombinant expression vectors. Any cell that is capable of expressing the fusion proteins of the present invention is suitable for use as a host cell. Such host cells include, but are not limited to, the cells of bacteria, yeast, insects, plants and animals. More preferably for certain PAMPs such as BLP, the host cell is a bacterial

cell. Even more preferably, the host cell is a bacterial cell that can appropriately modify (*e.g.*, lipidation, glycosylation) the PAMP domain of the fusion protein when such modification is necessary or desirable.

The present invention also provides methods of immunizing an animal with the vaccines of the present invention, where such methods include, but are not limited to, administering a vaccine parenterally, intravenously, orally, using suppositories, or via the mucosal surfaces. In one preferred embodiment the animal being vaccinated is a human.

The immune response can be measured using any suitable method including, but not limited to, direct measurement of peripheral blood lymphocytes, natural killer cell cytotoxicity assays, cell proliferation assays, immunoassays of immune cells and subsets, and skin tests for cell-mediated immunity.

The present invention also provides methods of treating a patient susceptible to an allergic response to an allergen by administering a vaccine of the present invention and thereby stimulating the TLR-mediated signaling pathway.

The present invention also provides methods of treating a patient susceptible to or suffering from Alzheimer's disease by administering a vaccine of the present invention in which the target antigen is a peptide or protein associated with Alzheimer's disease, including but not limited to amyloid- peptide.

The present invention further provides a method of stimulating an innate immune response in an animal and thereby enhancing the adaptive immune response to a foreign or self-antigen which comprises co-administering a PAMP with the foreign or self antigen.

The present invention also provides a vaccine which comprises a PAMP conjugated with a foreign or self antigen that stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

Additionally, the present invention provides a vaccine which comprises a PAMP conjugated with a foreign or self antigen which, when administered at a therapeutically active dose, stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

The present invention also provides a method of treatment comprising the steps of administering to an individual a vaccine which comprises a PAMP conjugated with a foreign or self antigen which stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

Additional embodiments of the present invention will be obvious to those skilled in the art of vaccine preparation and vaccine administration. Such obvious variations of the present invention are also contemplated by the present inventor.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows examples of alternative fusion proteins according to the present invention. Permutations and combinations of these fusion proteins can also be prepared according to the methods of the present invention.

Figure 2 shows a basic outline for generating different recombinant protein vaccines containing different antigens and a signal to trigger the innate immune response (PAMP). Each antigen is represented by a different shape of the central portion of the vaccine.

Figure 3 shows the BLP/Eα construct.

Figure 4 shows that BLP/Eα activates NF-κB in dose-dependent manner.

Figure 5 shows IL-6 production by dendritic cells stimulated with BLP/Eα.

Figure 6 shows the induction of dendritic cell activation and vaccine antigen processing and presentation by the MHC class-II pathway.

Figure 7 shows the immunostimulatory effect of the chimeric construct BLP/Eα on specific T-cells *in vitro*.

Figure 8 shows the effect of the chimeric construct, BLP/Eα, on specific T-cell proliferation *in vivo*.

Figure 9 shows that CpG-induced B-cell activation is dependent upon MyD88. MyD88 $^{-/-}$, MyD88-deficient cells; ICE $^{-/-}$, caspase-1-deficient cells; B10/ScCr, TLR4-deficient cells derived from C57BL/10ScCr mice; TLR2 $^{-/-}$, TLR2-deficient cells.

Figure 10 shows that IL-6 production by macrophages during CpG stimulation and CpG-DNA-induced IkBα degradation is mediated by a signaling pathway dependent on MyD88.

Figure 11 shows that wild-type and B10/ScCr dendritic cells, but not dendritic cells from MyD88$^{-/-}$ animals produce IL-12 when stimulated with CpG oligonucleotides.

Figure 12 shows activation of NF-κB by Flagellin fusions.

Figure 13 shows induction of NF-κB in macrophages by Flagellin fusions.

Figure 14 shows NF-κB activity in RAW κB cells.

Figure 15 shows SEQ ID NO: 3.

Figure 16 shows SEQ ID NO: 4.

Figure 17 shows SEQ ID NO: 5.

Figure 18 shows SEQ ID NO: 6.

Figure 19 shows SEQ ID NO: 7.

Figure 20 shows SEQ ID NO: 10.

Figure 21 shows SEQ ID NO: 11.

DETAILED DESCRIPTION OF THE INVENTION

1. General Description

The present invention discloses a novel strategy of vaccine design based on the inventor's recent findings in the field of innate immunity. This approach is not limited to any particular antigen or immunogenic portions or derivatives thereof (*e.g.*, microorganism-related, allergen-related or tumor-related, and the like) nor is it limited to any particular PAMP or immunostimulatory portions or immunostimulatory derivatives thereof. The term "vaccine", therefore, is used herein in a general sense to refer to any therapeutic or immunogenic or immunostimulatory composition that includes the features of the present invention. A more detailed definition of vaccine is disclosed elsewhere herein.

The activation of an adaptive immune response requires both the specific antigen or derivative thereof, and a signal (*e.g.* PAMP) that can induce the expression of B7 on the APCs. The present invention combines, in a single chimeric construct, both signals required for the induction of the adaptive immune responses - a signal recognized by the innate immune system (PAMP), and a signal recognized by an antigen receptor (antigen).

According to the present invention, neither the PAMP nor the antigen need consist of a polypeptide. However, either the PAMP or the antigen, or both, may be a peptide or polypeptide. In one embodiment of the present invention, recombinant DNA technology may be utilized in the production of chimeric constructs, for use in vaccines, when both the PAMP, or an immunogenic portion or derivative thereof, and the antigen, or an immunostimulatory portion or derivative thereof, are polypeptides.

Alternatively, recombinant techniques may also be utilized to produce a protein chimeric construct when a peptide mimetic is used in lieu of a non-protein antigen, such as a polysaccharide or a nucleic acid and the like, and/or a non-protein PAMP, such as a lipopolysaccharide, CpG-DNA, bacterial DNA, single or double-stranded viral RNA, phosphatidyl choline, lipoteichoic acids and the like, for example. The present invention contemplates in one embodiment the use of BLP, the bacterial outer membrane proteins (OMP), the outer surface proteins A (OspA) of bacteria, Flagellins and other DNA-encoded PAMPs in the recombinant production of chimeric constructs. These PAMPs are known to induce activation of the innate immune response and therefore would be particularly suitable for use in vaccine formulations. (Henderson *et al.* (1996) *Microbiol. Rev.* 60: 316-41). Furthermore, BLP has been shown to be recognized by TLRs. (Aliprantis *et al.* (1999) *Science* 285: 736-9). The details of the approach are described using BLP as the PAMP domain of a PAMP/antigen fusion protein; however any inducers of the innate immune system are equally applicable for such purpose in the present invention.

In another embodiment, one or more PAMP mimetics is substituted in place of a PAMP in a fusion protein.

This invention further provides methods for producing chimeric constructs where either the PAMP or an immunostimulatory portion or derivative thereof, or the antigen or an immunogenic portion or derivative thereof, or both the PAMP and the antigen are non-protein. Generally, these methods utilize chemical means to conjugate a PAMP to an antigen thereby producing a non-protein chimeric construct.

This invention further provides ways to exploit recombinant DNA technology in the synthesis of the peptide vaccines. Many of the surface antigens present on the pathogens of interest would not be amenable to encoding by nucleic acids as they are not proteins (*e.g.*, lipopolysaccharides) or possess low protein content (*e.g.*, peptidoglycans).

The present invention contemplates the use of peptide mimetics for these surface antigens or an immunogenic protein or derivative thereof, and the use of peptide mimetics in vaccines.

As discussed in greater detail herein, the present invention contemplates vaccines comprising chimeric constructs that comprise at least one antigen, or an immunogenic portion or derivative thereof, and at least one PAMP, or an immunogenic portion or derivative thereof. Thus, the present invention encompasses vaccines comprising fusion proteins where one or more protein antigens are linked to one or more protein PAMPs or a peptide mimetic of a PAMP. Preferably, the fusion protein has maximal immunogenicity and induces only a modest inflammatory response.

In instances in which a target antigen, or a domain of a target antigen, has a relatively low molecular weight and is not adequately immunogenic because of its small size, that antigen or antigen domain can act as a hapten and can be combined with a larger carrier molecule such that the molecular weight of the combined molecule will be high enough to evoke a strong immune response against the antigen. In one embodiment of this invention, the antigen itself serves as the carrier molecule. In another embodiment of this invention, the PAMP serves as the carrier molecule. In

yet another embodiment, a hapten is combined, by either fusion or conjugation, with the PAMP or the antigen domain of the vaccine to elicit an antibody response to the hapten. In yet another embodiment, which would, without limitation, be preferable when the molecular weight of both antigen and PAMP are low, the PAMP and the antigen are combined with a third molecule that serves as the carrier molecule. Such carrier molecule can be keyhole limpet hemocyanin or any of a number of carrier molecules for haptens that are known to the artisan. In yet another embodiment, a fusion protein contains an antigen or antigen domain, a PAMP or a portion of a PAMP or a PAMP mimetic, and a carrier protein or carrier peptide. Once again, such carrier protein can be keyhole limpet hemocyanin or any of a number of carrier proteins or carrier peptides for haptens that are known to the artisan. Increasing the number of antigens or antigen epitopes, by using multiple antigen proteins and/or multiple domains of the same antigen protein or of different antigen proteins and/or some combination of the foregoing, are contemplated in this invention. Also contemplated are fusion proteins in which the number of PAMPs or PAMP derivatives or PAMP mimetics is increased. It is within the skill of the artisan to determine the optimal ratio of PAMP to antigen domains to maximize immunogenicity and minimize inflammatory response.

2. Definitions

"Adaptive immunity" refers to the adaptive immune system, which involves two types of receptors generated by somatic mechanisms during the development of each individual organism. As used herein, the "adaptive immune system" refers to

both cellular and humoral immunity. Immune recognition by the adaptive immune system is mediated by antigen receptors.

"Adaptive immune response" refers to a response involving the characteristics of the "adaptive immune system" described above.

"Adapter molecule" refers to a molecule that can be transiently associated with some TLRs, mediates immunostimulation by molecules of the innate immune system, and mediates cytokine-induced signaling. "Adapter molecule" includes, but is not limited to, myeloid differentiation marker 88 (MyD88).

"Allergen" refers to an antigen, or a portion or derivative of an antigen, that induces an allergic or hypersensitive response.

"Amino acid polymer" refers to proteins, or peptides, and other polymers comprising at least two amino acids linked by a peptide bond(s), wherein such polymers contain either no non-peptide bonds or one or more non-peptide bonds. As used herein, "proteins" include polypeptides and oligopeptides.

"Antigen" refers to a substance that is specifically recognized by the antigen receptors of the adaptive immune system. Thus, as used herein, the term "antigen" includes antigens, derivatives or portions of antigens that are immunogenic and immunogenic molecules derived from antigens. Preferably, the antigens used in the present invention are isolated antigens. Antigens that are particularly useful in the present invention include, but are not limited to, those that are pathogen-related, allergen-related, or disease-related.

"Antigenic determinant" refers to a region on an antigen at which a given antigen receptor binds.

"Antigen-presenting cell" or "APC" or "professional antigen-presenting cell" or "professional APC" is a cell of the immune system that functions in triggering an adaptive immune response by taking up, processing and expressing antigens on its surface. Such effector cells include, but are not limited to, macrophages, dendritic cells and B cells.

"Antigen receptors" refers to the two types of antigen receptors of the adaptive immune system: the T-cell receptor (TCR) and the immunoglobulin receptor (IgR), which are expressed on two specialized cell types, T-lymphocytes and B-lymphocytes, respectively. The secreted form of the immunoglobulin receptor is referred to as antibody. The specificities of the antigen receptors are generated at random during the maturation of the lymphocytes by the processes of somatic gene rearrangement, random pairing of receptor subunits, and by a template-independent addition of nucleotides to the coding regions during the rearrangement.

"Chimeric construct" refers to a construct comprising an antigen and a PAMP, or PAMP mimetic, wherein the antigen and the PAMP are comprised of molecules such as amino acids, amino acid polymers, nucleotides, nucleotide polymers, carbohydrates, carbohydrate polymers, lipids, lipid polymers or other synthetic or naturally occurring chemicals or chemical polymers. As used herein, a "chimeric construct" refers to constructs wherein the antigen is comprised of one type of molecule in association with a PAMP or PAMP mimetic, which is comprised of either the same type of molecule or a different type of molecule.

"CpG" refers to a dinucleotide in which an unmethylated cytosine (C) residue occurs immediately 5' to a guanosine (G) residue. As used herein, "CpG-DNA"

refers to a synthetic CpG repeat, intact bacterial DNA containing CpG motifs, or a CpG-containing derivative thereof. The immunostimulatory effect of CpG-DNA on B-cells is mediated through a TLR and is dependent upon a "protein adapter molecule".

"Derivative" refers to any molecule or compound that is structurally related to the molecule or compound from which it is derived. As used herein, "derivative" includes peptide mimetics (*e.g.*, PAMP mimetics).

"Domain" refers to a portion of a protein with its own function. The combination of domains in a single protein determines its overall function. An "antigen domain" comprises an antigen or an immunogenic portion or derivative of an antigen. A "PAMP domain" comprises a PAMP or a PAMP mimetic or an immunostimulatory portion or derivative of a PAMP or a PAMP mimetic.

"Fusion protein" and "chimeric protein" both refer to any protein fusion comprising two or more domains selected from the following group consisting of: proteins, peptides, lipoproteins, lipopeptides, glycoproteins, glycopeptides, mucoproteins, mucopeptides, such that at least two of the domains are either from different species or encoded by different genes or such that one of the two domains is found in nature and the second domain is not known to be found in nature or such that one of the two domains resembles a molecule found in nature and the other does not resemble that same molecule. The term "fusion protein" also refers to an antigen or an immunogenic portion or derivative thereof which has been modified to contain an amino acid sequence that results in post-translational modification of that amino acid sequence or a portion of that sequence, wherein the post-translationally modified

sequence is a ligand for a PRR. As yet another definition of a fusion protein, in the foregoing sentence, the amino acid sequence that results in post-translational modification to form a ligand for a PRR can comprise a consensus sequence, or that amino acid sequence can contain a leader sequence and a consensus sequence.

"Hapten" refers to a small molecule that is not by itself immunogenic but can bind antigen receptors and can combine with a larger carrier molecule to become immunogenic.

"In association with" refers to a reversible union between two chemical entities, whether alike or different, to form a more complex substance.

"In combination with" refers to either a reversible or irreversible (*e.g.* covalent) union between two chemical entities, whether alike or different, to form a more complex substance.

"Immunostimulatory" refers to the ability of a molecule to activate either the adaptive immune system or the innate immune system. As used herein, "antigens" are examples of molecules that are capable of stimulating the adaptive immune system, whereas PAMPs or PAMP mimetics are examples of molecules that are capable of stimulating the innate immune system. As used herein, "activation" of either immune system includes the production of constituents of humoral and/or cellular immune responses that are reactive against the immunostimulatory molecule.

"Innate immunity" refers to the innate immune system, which, unlike the "adaptive immune system", uses a set of germline-encoded receptors for the recognition of conserved molecular patterns present in microorganisms.

"Innate immune response" refers to a response involving the characteristics of the "innate immune system" described above.

"Isolated" refers to a substance, cell, tissue, or subcellular component that is separated from or substantially purified with respect to a mixture or naturally occurring material.

"Linker" refers to any chemical entity that links one chemical moiety to another chemical moiety. Thus, something that chemically or physically connects a PAMP and an antigen is a linker. Examples of linkers include, but are not limited to, complex or simple hydrocarbons, nucleosides, nucleotides, nucleotide phosphates, oligonucleotides, polynucleotides, nucleic acids, amino acids, small peptides, polypeptides, carbohydrates (*e.g.*, monosaccharides, disaccharides, trisaccharides), and lipids. Additional examples of linkers are provided in the Detailed Description Selection included herein. Without limitation, the present invention also contemplates using a peptide bond or an amino acid or a peptide linker to link a polypeptide PAMP and a polypeptide antigen. The present invention further contemplates preparing such a linked molecule by recombinant DNA procedures. A linker can also function as a spacer.

"Malignant" refers to an invasive, spreading tumor.

"Microorganism" refers to a living organism too small to be seen with the naked eye. Microorganisms include, but are not limited to bacteria, fungi, protozoans, microscopic algae, and also viruses.

"Mimetic" refers to a molecule that closely resembles a second molecule and has a similar effect or function as that of the second molecule.

"Moiety" refers to one of the component parts of a molecule. While there are normally two moieties in a single molecule, there may be more than two moieties in a single molecule.

"Molecular pattern" refers to a chemical structure or motif that is typically a component of microorganisms, or certain other organisms, but which is not typically produced by normal human cells or by other normal animal cells. Molecular patterns are found in, or composed of, the following types of molecules: lipopolysaccharides, peptidoglycans, lipoteichoic acids, phosphatidyl cholines, lipoproteins, bacterial DNAs, viral single and double-stranded RNAs, certain viral glycoproteins, unmethylated CpG-DNAs, mannans, and a variety of other bacterial, fungal and yeast cell wall components and the like.

"Non-protein chimeric construct" or "non-protein chimera" refers to a "chimeric construct" wherein either the antigen or the PAMP or the PAMP mimetic, or two or more of them, is not an amino acid polymer.

"Pathogen-Associated Molecular Pattern" or "PAMP" refers to a molecular pattern found in a microorganism but not in humans, which, when it binds a PRR, can trigger an innate immune response. Thus, as used herein, the term "PAMP" includes any such microbial molecular pattern and is not limited to those associated with pathogenic microorganisms or microbes. As used herein, the term "PAMP" includes a PAMP, derivative or portion of a PAMP that is immunostimulatory, and any immunostimulatory molecule derived from any PAMP. These structures, or derivatives thereof, are potential initiators of innate immune responses, and therefore, ligands for PRRs, including Toll receptors and TLRs. "PAMPs" are

immunostimulatory structures that are found in, or composed of molecules including, but not limited to, lipopolysaccharides; phosphatidyl choline; glycans, including peptidoglycans; teichoic acids, including lipoteichoic acids; proteins, including lipoproteins and lipopeptides; outer membrane proteins (OMPs), outer surface proteins (OSPs) and other protein components of the bacterial cell walls and Flagellins; bacterial DNAs; single and double-stranded viral RNAs; unmethylated CpG-DNAs; mannans; mycobacterial membranes; porins; and a variety of other bacterial and fungal cell wall components, including those found in yeast. Additional examples of PAMPs are provided in the Detailed Description section included herein.

"PAMP/antigen conjugate" refers to an antigen and a PAMP or PAMP mimetic that are covalently or noncovalently linked. A conjugate may be comprised of a protein PAMP or antigen and a non-protein PAMP or antigen.

"PAMP/antigen fusion" or "PAMP/antigen chimera" refers to any protein fusion formed between a PAMP or PAMP mimetic and an antigen.

"Passive immunization" refers to the administration of antibodies or primed lymphocytes to an individual in order to confer immunity.

"PAMP mimetic" refers to a molecule that, although it does not occur in microorganisms, is analogous to a PAMP in that it can bind to a PRR and such binding can trigger an innate immune response. A PAMP mimetic can be a naturally-occurring molecule or a partially or totally synthetic molecule. As an example, and not by way of limitation, certain plant alkaloids, such as taxol, are PRR ligands, have an immunostimulatory effect on the innate immune system, and thus behave as PAMP mimetics. (Kawasaki *et al.* (2000) *J. Biol. Chem.* 275(4): 2251-2254).

"Pattern Recognition Receptor" or "PRR" refers to a member of a family of receptors of the innate immune system that, upon binding a PAMP, an immunostimulatory portion or derivative thereof, can initiate an innate immune response. Members of this receptor family are structurally different and belong to several different protein families. Some of these receptors recognize PAMPs directly (*e.g.*, CD14, DEC205, collectins), while others (*e.g.*, complement receptors) recognize the products generated by PAMP recognition. Members of these receptor families can, generally, be divided into three types: 1) humoral receptors circulating in the plasma; 2) endocytic receptors expressed on immune-cell surfaces, and 3) signaling receptors that can be expressed either on the cell surface or intracellularly. Cellular PRRs may be expressed on effector cells of the innate immune system, including cells that function as professional APCs in adaptive immunity, and also on cells such as surface epithelia that are the first to encounter pathogens during infection. PRRs may also induce the expression of a set of endogenous signals, such as inflammatory cytokines and chemokines. Examples of PRRs useful for the present invention include, but are not limited to, the following: C-type lectins (*e.g.*, humoral, such as collectins (MBL), and cellular, such as macrophage C-type lectins, macrophage mannose receptors, DEC205); proteins containing leucine-rich repeats (*e.g.*, Toll receptor and TLRs, CD14, RP105); scavenger receptors (*e.g.*, macrophage scavenger receptors, MARCO, WC1); and pentraxins (*e.g.*, C-reactive proteins, serum, amyloid P, LBP, BPIP, CD11b,C and CD18.

"Peptide mimetic" refers to a protein or peptide that closely resembles a non-protein molecule and has a similar effect or function to the non-protein molecule.

Alternatively, a peptide mimetic can be a non-protein molecule or non-peptide molecule that closely resembles a peptide or protein and has a similar effect or function to the peptide or protein.

"Pharmaceutically acceptable carrier" refers to a carrier that can be tolerated by a recipient animal, typically a mammal.

"Protein chimeric construct" refers to a chimeric construct wherein both the antigen and the PAMP or PAMP mimetic are amino acid polymers.

"Recombinant" refers to genetic material that is produced by splicing genes, gene derivatives or other genetic material. As used herein, "recombinant" also refers to the products produced from recombinant genes (*e.g.* recombinant protein).

"Spacer" refers to any chemical entity placed between two chemical moieties that serves to physically separate the latter two moieties. Thus, a chemical entity placed between a PAMP or PAMP mimetic and an antigen is a spacer. Examples of spacers include, but are not limited to, nucleic acids (*e.g.* untranscribed DNA between two stretches of transcribed DNA), amino acids, carbohydrates (*e.g.*, monosaccharides, disaccharides, trisaccharides), and lipids.

"Strong immune response" refers to an immune response, induced by the chimeric construct, that has about the same intensity or greater than the response induced by an antigen mixed with Complete Freund's Adjuvant (CFA).

"Therapeutically effective amount" refers to an amount of an agent (*e.g.*, a vaccine) that can produce a measurable positive effect in a patient.

"Toll-like receptor" (TLR) refers to any of a family of receptor proteins that are homologous to the *Drosophila melanogaster* Toll protein. TLRs also refer to type

I transmembrane signaling receptor proteins that are characterized by an extracellular leucine-rich repeat domain and an intracellular domain homologous to that of the interleukin 1 receptor. The TLR family includes, but is not limited to, mouse TLR2 and TLR4 and their homologues, particularly in other species including humans. This invention also defines Toll receptor proteins and TLRs wherein the nucleic acids encoding such proteins have at least about 70% sequence identity, more preferably, at least about 80% sequence identity, even more preferably, at least about 85% sequence identity, yet more preferably at least about 90% sequence identity, and most preferably at least about 95% sequence identity to the nucleic acid sequence encoding the Toll protein and the TLR proteins TLR2, TLR4 and other members of the TLR family. In addition, this invention also contemplates Toll receptors and TLRs wherein the amino acid sequences of such Toll receptors and TLRs have at least about 70% sequence identity, more preferably, at least about 80% sequence identity, even more preferably, at least about 85% sequence identity, yet more preferably at least about 90% sequence identity, and most preferably at least about 95% sequence identity to the amino acid sequences of the Toll protein and the TLRs, TLR2, TLR4 and their homologues.

"Tumor" refers to a mass of proliferating cells lacking, to varying degrees, normal growth control. As used herein, "tumors" include, at one extreme, slowly proliferating "benign" tumors, to, at the other extreme, rapidly proliferating "malignant" tumors that aggressively invade neighboring tissues.

"Vaccine" refers to a composition comprising an antigen, and optionally other ancillary molecules, the purpose of which is to administer such compositions to a

subject to stimulate an immune response specifically against the antigen and preferably to engender immunological memory that leads to mounting of an immune response should the subject encounter that antigen at some future time. Examples of other ancillary molecules are adjuvants, which are non-specific immunostimulatory molecules, and other molecules that improve the pharmacokinetic and/or pharmacodynamic properties of the antigen. Conventionally, a vaccine usually consists of the organism that causes a disease (suitably attenuated or killed) or some part of the pathogenic organism as the antigen. Attenuated organisms, such as attenuated viruses or attenuated bacteria, are manipulated so that they lose some or all of their ability to grow in their natural host. There are now a range of biotechnological approaches used to producing vaccines. (*See, e.g.*, W. Bains (1998) Biotechnology From A to Z, Second Edition, Oxford University Press). The various methods include, but are not limited to, the following:

1) Viral vaccines consisting of genetically altered viruses. The viruses can be engineered so that they are harmless but can still replicate (albeit inefficiently, sometimes) in cultured animal cells. Another approach is to clone the gene for a protein from a pathogenic virus into another, harmless virus, so that that resulting, engineered virus has certain immunologic properties of the pathogenic virus but does not cause any disease. Examples of the latter method include, but are not limited to, altered vaccinia and adenoviruses used as rabies vaccines for distribution with meat bait, and a vaccinia virus engineered to produce haemagglutinin and fusion proteins of rindepest virus of cattle;

2) Enhanced bacterial vaccines consisting of bacteria genetically engineered to enhance their value as vaccines when the bacteria are dead *(e.g., E. coli* vaccine for pigs, bacterial vaccine for furunculosis in salmon). Recombinant DNA techniques can be used to delete pathogenesis-causing genes in the bacteria or to engineer the protective epitope from a pathogen into a safe bacterium;

3) Biopharmaceutical vaccines consist of proteins, or portions of proteins, that are the same as the proteins in a viral, fungal or bacterial coat or wall, which can be made by recombinant DNA methods;

4) Multiple antigen peptides (MAPs) are peptide vaccines that are chemically attached (usually on a polylysine backbone), enabling several vaccines to be delivered at the same time;

5) Polyprotein vaccines consist of a single protein made by genetic engineering so that the different peptides from the organisms of interest form part of a continuous polypeptide chain; and

6) Vaccines produced in transgenic plants that can be used as food to provide oral vaccines (*e.g.*, vaccine delivery by eating bananas).

3. Specific Embodiments

A. Fusion Proteins

The present invention is based in part on the unexpected discovery that vaccines comprising chimeric constructs of a PAMP and an antigen (*e.g.*, the fusion protein BLP/Eα) exhibit the essential immunological characteristics or properties expected of a conventional vaccine supplemented with an adjuvant.

In one aspect, the present invention is based on the finding that BLP/Eα induces activation of NF-κB and production of IL-6 in macrophages and dendritic cells, respectively, demonstrating that the vaccine is capable of activating the innate immune system. The activity of BLP/Eα is comparable to that of LPS, and is not due to endotoxin contamination, as demonstrated by the lack of inhibition by polymyxin B.

In another aspect, the present invention is based on the finding that the BLP/Eα fusion protein induces maturation of dendritic cells, as demonstrated by the induction of the cell surface expression of the co-stimulatory molecule, B7.2. Additionally, BLP/Eα is appropriately targeted to the antigen processing and presentation pathway, and a functional Eα peptide/MHC class-II complex is generated. This result is demonstrated by FACS analysis using an antibody specific for the Eα peptide complexed with MHC class-II.

Moreover, the present invention is based on the surprising discovery that a recombinant vaccine comprising a BLP/Ea chimeric construct activates antigen-specific T-cell responses *in vitro* by stimulating dendritic cell activation and generating a specific ligand (Eα/MHC-II) for the T-cell receptor. Furthermore, the results of immunization of mice with BLP/Eα and the resultant antigen-specific T-cell responses demonstrate that the recombinant vaccine activates antigen-specific T-cell responses *in vivo*. For comparison, mice were immunized with Eα peptide mixed with Complete Freund's Adjuvant (CFA). The recombinant vaccine of the present invention induced an immune response in the mice that is stronger than that produced by Eα peptide mixed with CFA.

The present invention is also based on the surprising discovery that immunization with the recombinant vaccines that comprise the chimeric constructs of the present invention induce a minimal inflammatory reaction when compared to that induced by an adjuvant. However, as noted above, in spite of a reduced inflammatory response, the vaccine unexpectedly induced a strong immune response. Thus, the vaccine approach described in the present invention minimizes an undesired side effect (*e.g.*, an excessive inflammatory reaction) yet induces a very potent and specific immune response. The present invention also provides fusion proteins comprising at least one antigen molecule or antigen domain and at least one PAMP or PAMP mimetic for use as vaccines. Preferably, the fusion protein has maximal immunogenicity and induces only a modest inflammatory response. Increasing the number of antigens or antigen epitopes, by using multiple antigen proteins and/or multiple domains of the same antigen protein or of different antigen proteins, and/or some combination of the foregoing, are contemplated in this invention. It is within the skill of the artisan to determine the optimal ratio of PAMP to antigen molecules to maximize immunogenicity and minimize or control the inflammatory response.

There are several advantages of using a fusion system for the production of recombinant polypeptides. First, heterologous proteins and peptides are often degraded by host proteases; this may be avoided, especially for small peptides, by using a gene fusion expression system. Second, general and efficient purification schemes are established for several fusion partners. The use of a fusion partner as an affinity handle allows rapid isolation of the recombinant peptide. Third, by using different fusion partners, the recombinant product may be localized to different

compartments or it might be secreted; such strategy could lead to facilitation of purification of the fusion partner and/or directed compartmentalization of the fusion protein.

Additionally, various methods are available for chemical or enzymatic cleavage of the fusion protein that provides efficient strategies to obtain the desired cleavage product in large quantities. Frequently employed fusion systems are the Staphylococcal protein A fusion system and the synthetic ZZ variant which have IgG affinity and have been used for the generation of antibodies against short peptides; the glutathione S-transferase fusion system (Smith *et al.* (1988) *Gene* 60); the β-galactosidase fusion system; and the trpE fusion system (Yansura (1990) *Methods Enzym.* 185: 61). Some of these systems are commercially available as kits, including vectors, purification components and detailed instructions.

The present invention also contemplates modified fusion proteins having affinity for metal (metal ion) affinity matrices, whereby one or more specific metal-binding or metal-chelating amino acid residues are introduced, by addition, deletion, or substitution, into the fusion protein sequence as a tag. Optimally, the fusion partner, *e.g.*, the antigen or PAMP sequence, is modified to contain the metal-chelating amino acid tag; however the antigen or PAMP could also be altered to provide a metal-binding site if such modifications could be achieved without adversely effecting a ligand-binding site, an active site, or other functional sites, and/or destroying important tertiary structural relationships in the protein. These metal-binding or metal-chelating residues may be identical or different, and can be selected from the group consisting of cysteine, histidine, aspartate, tyrosine,

tryptophan, lysine, and glutamate, and are located so to permit binding or chelation of the expressed fusion protein to a metal. Histidine is the preferred metal-binding residue. The metal-binding/chelating residues are situated with reference to the overall tertiary structure of the fusion protein to maximize binding/chelation to the metal and to minimize interference with the expression of the fusion protein or with the protein's biological activity.

A fusion sequence of an antigen, PAMP and a tag may optionally contain a linker peptide. The linker peptide might separate a tag from the antigen sequence or the PAMP sequence. If the linker peptide so used encodes a sequence that is selectively cleavable or digestible by conventional chemical or enzymatic methods, then the tag can be separated from the rest of the fusion protein after purification. For example, the selected cleavage site within the tag may be an enzymatic cleavage site. Examples of suitable enzymatic cleavage sites include sites for cleavage by a proteolytic enzyme, such as enterokinase, Factor Xa, trypsin, collagenase, and thrombin. Alternatively, the cleavage site in the linker may be a site capable of cleavage upon exposure to a selected chemical (*e.g.*, cyanogen bromide, hydroxylamine, or low pH).

Cleavage at the selected cleavage site enables separation of the tag from the antigen/PAMP fusion protein. The antigen/PAMP fusion protein may then be obtained in purified form, free from any peptide fragment to which it was previously linked for ease of expression or purification. The cleavage site, if inserted into a linker useful in the fusion sequences of this invention, does not limit this invention.

Any desired cleavage site, of which many are known in the art, may be used for this purpose.

The optional linker peptide in a fusion protein of the present invention might serve a purpose other than the provision of a cleavage site. As an example, and not by limitation, the linker peptide might be inserted between the PAMP and the antigen to prevent or alleviate steric hindrance between the two domains. In addition, the linker sequence might provide for post-translational modification including, but not limited to, *e.g.*, phosphorylation sites, biotinylation sites, sulfation sites, carboxylation sites, lipidation sites, glycosylation sites and the like.

In one embodiment, the fusion protein of this invention contains an antigen sequence fused directly at its amino or carboxyl terminal end to the sequence of a PAMP. In another embodiment, the fusion protein of this invention, comprising an antigen and a PAMP sequence, is fused directly at its amino or carboxyl terminal end to the sequence of a tag. The resulting fusion protein is a soluble cytoplasmic fusion protein. In another embodiment, the fusion sequence further comprises a linker sequence interposed between the antigen sequence and a PAMP sequence or sequence of a tag. This fusion protein is also produced as a soluble cytoplasmic protein.

B. Antigens

As used herein, an "antigen" is any substance that induces a state of sensitivity and/or immune responsiveness after any latent period (normally, days to weeks in humans) and that reacts in a demonstrable way with antibodies and/or immune cells of the sensitized subject *in vivo* or *in vitro*. Examples of antigens include, but are not limited to, (1) microbial-related antigens, especially antigens of pathogens such as

viruses, fungi or bacteria, or immunogenic molecules derived from them; (2) "self" antigens, collectively comprising cellular antigens including cells containing normal transplantation antigens and/or tumor-related antigens, RR-Rh antigens and antigens characteristic of, or specific to particular cells or tissues or body fluids; (3) allergen-related antigens such as those associated with environmental allergens (*e.g.*, grasses, pollens, molds, dust, insects and dander), occupational allergens (*e.g.*, latex, dander, urethanes, epoxy resins), food (*e.g.*, shellfish, peanuts, eggs, milk products), drugs (*e.g.*, antibiotics, anesthetics) and (4) vaccines (e.g., flu vaccine).

Antigen processing and recognition of displayed peptides by T-lymphocytes depends in large part on the amino acid sequence of the antigen rather than the three-dimensional structure of the antigen. Thus, the antigen portion used in the vaccines of the present invention can contain epitopes or specific domains of interest rather than the entire sequence. In fact, the antigenic portions of the vaccines of the present invention can comprise one or more immunogenic portions or derivatives of the antigen rather than the entire antigen. Additionally, the vaccine of the present invention can contain an entire antigen with intact three-dimensional structure or a portion of the antigen that maintains a three-dimensional structure of an antigenic determinant, in order to produce an antibody response by B-lymphocytes against a spatial epitope of the antigen.

1. Pathogen-Related Antigens. Specific examples of pathogen-related antigens include, but are not limited to, antigens selected from the group consisting of vaccinia, avipox virus, turkey influenza virus, bovine leukemia virus, feline leukemia virus, avian influenza, chicken pneumovirosis virus, canine parvovirus, equine

influenza, FHV, Newcastle Disease Virus (NDV), Chicken/Pennsylvania/1/83 influenza virus, infectious bronchitis virus; Dengue virus, measles virus, Rubella virus, pseudorabies, Epstein-Barr Virus, HIV, SIV, EHV, BHV, HCMV, Hantaan, *C. tetani*, mumps, Morbillivirus, Herpes Simplex Virus type 1, Herpes Simplex Virus type 2, Human cytomegalovirus, Hepatitis A Virus, Hepatitis B Virus, Hepatitis C Virus, Hepatitis E Virus, Respiratory Syncytial Virus, Human Papilloma Virus, Influenza Virus, *Salmonella*, *Neisseria*, *Borrelia*, *Chlamydia*, *Bordetella*, and *Plasmodium and Toxoplasma*, *Cryptococcus*, *Streptococcus*, *Staphylococcus*, *Haemophilus*, *Diptheria*, *Tetanus*, *Pertussis*, *Escherichia*, *Candida*, *Aspergillus*, *Entamoeba*, *Giardia*, and *Trypanasoma*.

2. Cancer-Related Antigens. The methods and compositions of the present invention can also be used to produce vaccines directed against tumor-associated protein antigens such as melanoma-associated antigens, mammary cancer-associated antigens, colorectal cancer-associated antigens, prostate cancer-associated antigens and the like.

Specific examples of tumor-related or tissue-specific protein antigens useful in such vaccines include, but are not limited to, antigens selected from the group in the following table.

Cancer type	Antigens
Prostate	prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1
Melanoma	TRP-2, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside
Breast	Her2-neu, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF -1 anti-apoptotic factor, HOM-Mel-40/SSX2

Testis	MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1
Colorectal	EGFR, CEA
Lung	MAGE D, EGFR
Ovarian	Her-2neu
Several cancers	NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53 (especially mutated versions), EGFR
Miscellaneous tumor antigens	CDC27 (including the mutated form of the protein), triosephosphate isomerase

In order for tumors to give rise to proliferating and malignant cells, they must become vascularized. Strategies that prevent tumor vascularization have the potential for being therapeutic. The methods and compositions of the present invention can also be used to produce vaccines directed against tumor vascularization. Examples of target antigens for such vaccines are vascular endothelial growth factors, vascular endothelial growth factor receptors, fibroblast growth factors and fibroblast growth factor receptors and the like.

3. Allergen-Related Antigens. The methods and compositions of the present invention can be used to prevent or treat allergies and asthma. According to the present invention, one or more protein allergens can be linked to one or more PAMPs, producing a PAMP/allergen chimeric construct, and administered to subjects that are allergic to that antigen. Thus, the methods and compositions of the present invention can also be used to construct vaccines that may suppress allergic reactions. In this case, the allergen is associated with or combined with a PAMP, including but not limited to BLP or Flagellin, that can initiate a Th1 response upon binding to a TLR. Initiation of innate immunity via a TLR, for example, tends to be characterized by production and secretion of cytokines, such as IL-12, that elicit a so-called Th1 response in a subject, rather than the typical Th2 response that triggers B-cells to

produce immunoglobulin E, the initiator of typical allergic and/or hypersensitive responses. IL-12 produced by dendritic cells and macrophages upon PAMP binding to their TLRs will direct T-cell differentiation into Th1 effector cells. Cytokines produced by Th1 cells, such as Interferon-gamma, will block the differentiation of IL-4 producing Th2 cells and would thus prevent production of antibodies of the IgE isotype, which are responsible for allergic responses.

Specific examples of allergen-related protein antigens useful in the methods and compositions of the present invention include, but are not limited to: allergens derived from pollen, such as those derived from trees such as Japanese cedar (*Cryptomeria, Cryptomeria japonica*), grasses (*Gramineae*), such as orchard-grass (*Dactylis, Dactylis glomerata*), weeds such as ragweed (*Ambrosia, Ambrosia artemisiifolia*); specific examples of pollen allergens including the Japanese cedar pollen allergens Cry j 1 (*J. Allergy Clin. Immunol.* (1983)71: 77-86) and Cry j 2 (*FEBS Letters* (1988) 239: 329-332), and the ragweed allergens Amb a I.1, Amba I.2, Amb a I.3, Amb a I.4, Amb a II etc.; allergens derived from fungi (*Aspergillus, Candida, Alternaria*, etc.); allergens derived from mites (allergens from *Dermatophagoides pteronyssinus, Dermatophagoides farinae* etc.; specific examples of mite allergens including Der p I, Der p II, Der p III, Der p VII, Der f I, Der f II, Der f III, Der f VII *etc.*); house dust; allergens derived from animal skin debris, feces and hair (for example, the feline allergen Fel d I); allergens derived from insects (such as scaly hair or scale of moths, butterflies, *Chironomidae* etc., poisons of the *Vespidae*, such *as Vespa mandarinia*); food allergens (eggs, milk, meat, seafood, beans, cereals, fruits, nuts and vegetables *etc.*); allergens derived from parasites (such as roundworm

and nematodes, for example, *Anisakis*); and protein or peptide based drugs (such as insulin). Many of these allergens are commercially available.

In another embodiment, prophylactic treatment of chronic allergies can be accomplished by the administration of a protein PAMP. In a preferred embodiment, the PAMP of the prophylactic vaccine is an OMP, more preferably OspA, and most preferably BLP. Alternatively, Flagellin can be used as the PAMP.

4. Other Disease Antigens. Also contemplated in this invention are vaccines directed against antigens that are associated with diseases other than cancer, allergy and asthma. As one example of many, and not by limitation, an extracellular accumulation of a protein cleavage product of β-amyloid precursor protein, called "amyloid-β peptide", is associated with the pathogenesis of Alzheimer's disease. (Janus *et al.*, *Nature* (2000) 408: 979-982; Morgan *et al.*, *Nature* (2000) 408: 982-985). Thus, the chimeric construct used in the vaccines of the present invention can include amyloid-β peptide, or antigenic domains of amyloid-β peptide, as the antigenic portion of the construct, and a PAMP or PAMP mimetic. Examples of other diseases in which vaccines might be generated against self proteins or self peptides are shown in the following table.

Disease	Antigens
Autoimmune diseases	disease-linked HLA-alleles (e.g., HLA-DRB1, HLA-DR1, HLA-DR6 B1 proteins or fragments thereof, chain genes); TCR chain sub-groups; CD11a (leukocyte function-associated antigen 1; LFA-1); IFNγ; IL-10;TCR analogs; IgR analogs; 21-hydoxylase (for Addison's disease); calcium sensing receptor (for acquired

	hypoparathyroidism); tyrosinase (for vitiligo)
Cardiovascular disease	LDL receptor
Diabetes	glutamic acid decarboxylase (GAD);insulin B chain; PC-1; IA-2, IA-2b; GLIMA-38
Epilepsy	NMDA

C. PAMPs

PAMPs are discrete molecular structures that are shared by a large group of microorganisms. They are conserved products of microbial metabolism, which are not subject to antigenic variability and are distinct from self-antigens. (Medzhitov *et al.* (1997) *Current Opinion in Immunology* 9: 4).

PAMPs can be composed of or found in, but are not limited to, the following types of molecules: Flagellins, lipopolysaccharides (LPS), porins, lipid A-associated proteins (LAP), lipopolysaccharides, fimbrial proteins, unmethylated CpG motifs, bacterial DNAs, double-stranded viral RNAs, mannans, cell wall-associated proteins, heat shock proteins, glycoproteins, lipids, cell surface polysaccharides, glycans (*e.g.*, peptidoglycans), phosphatidyl cholines, teichoic acids (*e.g.*, lipoteichoic acids), mycobacterial cell wall components/membranes, bacterial lipoproteins (BLP), outer membrane proteins (OMP), and outer surface protein A (Osp A). (Henderson *et al.* (1996) *Microbiol. Review* 60: 316; Medzhitov *et al.* (1997) *Current Opinion in Immunology* 9: 4-9).

The preferred PAMPs of the present invention include those that contain a DNA-encoded protein component, such as BLP, *Neisseria* porin, OMP, Flagellin and OspA, as these can be used as fusion partners to prepare the preferred embodiment of

the invention, i.e., fusion proteins comprising a PAMP and an antigen, preferably a self-antigen. One preferable PAMP for use in the present invention is BLP because BLP is known to induce activation of the innate immune response (Henderson *et al.* (1996) *Microbiol. Review* 60: 316) and has been shown to be recognized by TLRs (Aliprantis *et al.* (1999) *Science* 285: 763). Flagellin has similarly been demonstrated to induce features of innate immunity (Eaves-Pyles *et al.*, (2001) *J. Immunol.* 166:1248; Gewirtz *et al.*, (2001) *J Clin Invest.* 107: 99); Aderem, *Presentation at Keystone Symposium, Keystone, CO, 2001*).

Additionally, the present invention contemplates derivatives, portions, parts, or peptides of PAMPs that are recognized by the innate immune system for generating vaccines. As used herein, the terms "fragments of PAMPs", "portions of PAMPs", "parts of PAMPs" and "peptides of PAMPs", all refer to an immunostimulatory part of an entire PAMP molecule. Thus, the PAMPs used in the vaccines of the present invention can comprise an immunostimulatory portion or derivative of the PAMP rather than the entire PAMP, for example E. Coli murein lipoprotein amino acids 1 to 24.

In another embodiment, the present invention contemplates peptide mimetics of non-protein PAMPs. Peptide mimetics of polysaccharides and peptidoglycans are examples of peptide mimetics which can be used in the present invention. The present invention contemplates using phage selection methods to identify peptide mimetics of these non-protein PAMPs. For example, an antibody raised against a non-protein PAMP can be used to screen a phage library containing randomized short-peptide sequences. Selected sequences are isolated and assayed to determine

their usefulness as a protein derivative of a non-protein PAMP in the chimeric constructs of the present invention. Such peptide mimetics are useful to produce the recombinant vaccines disclosed herein.

In yet another embodiment, the present invention contemplates further examples of PAMP mimics or PAMP mimetics in which analogs of amino acids and/or peptides are substituted for the amino acid and/or peptide residues, respectively, of a peptide-containing PAMP or a protein PAMP.

In another embodiment, the chimeric construct is a construct comprising CpG or CpG-DNA, and an antigen. The CpG or CpG-DNA can be conjugated to a protein or non-protein antigen. In addition, peptide mimetics of CpG or CpG-DNA, that mimic the structural, functional, antigenic or immunogenic properties of CpG, can be produced and used to generate an antigen-PAMP (where PAMP is a CpG peptide mimetic) protein chimeric construct. This chimeric construct can be produced by recombinant DNA techniques and the expressed fusion protein can be used in the compositions and methods of the present invention.

D. Peptide Mimetics

This invention also includes a mimetic of the three-dimensional structure of a PAMP or antigen. In particular, this invention also includes peptides that closely resemble the three-dimensional structure of non-peptide PAMPs and antigens. Such peptides provide alternatives to non-polypeptide PAMPs or antigens, respectively, by providing the advantages of, for example: more economical production, greater chemical stability, enhanced pharmacological properties (half-life, absorption,

potency, efficacy, and/or altered specificity (*e.g.*, a broad-spectrum of biological activities), and other advantages.

Conversely, analogs of PAMP and/or antigen proteins can be synthesized such that one or both consists partially or entirely of amino acid and /or peptide analogs. Such analogs can contain non-naturally-occurring amino acids, or naturally-occurring amino acids that do not commonly occur in proteins, including but not limited to, D-amino acids or amino acids such as β-alanine, ornithine or canavanine, and the like, many of which are known in the art. Alternatively, analogs of PAMPs and/or antigens can be synthesized such that one or both consists partially or entirely of peptide analogs containing non-peptide bonds, many examples of which are known in the art. Such analogs may provide greater chemical stability, enhanced pharmacological properties (half-life, absorption, potency, efficacy, etc.) and/or altered specificity (*e.g.*, a broad-spectrum of biological activities) when compared with the naturally-occurring PAMP and/or antigen as well as other advantages.

In one form, the contemplated molecular structures are peptide-containing molecules that mimic elements of protein secondary structure. (see, for example, Johnson *et al.* (1993) Peptide Turn Mimetics, in Biotechnology and Pharmacy, Pezzuto *et al.*, (editors) Chapman and Hall). Such molecules are expected to permit molecular interactions similar to the natural molecule.

In another form, analogs of peptides are commonly used in the pharmaceutical industry as non-peptide drugs with properties analogous to those of a subject peptide. These types of non-peptide compounds are also referred to as "peptide mimetics" or "peptidomimetics" (Fauchere (1986) *Adv. Drug Res.*15, 29-69; Veber *et al.* (1985)

Trends Neurosci. 8: 392-396; Evans *et al.* (1987) *J. Med. Chem.* 30: 1229-1239) and are usually developed with the aid of computerized molecular modeling.

Peptide mimetics that are structurally similar to therapeutically useful peptides may be used to produce an equivalent therapeutic or prophylactic effect. Generally, peptide mimetics are structurally similar to a paradigm polypeptide (*e.g.*, a polypeptide that has a biochemical property or pharmacological activity), but have one or more peptide linkages optionally replaced by a linkage selected from the group consisting of: $-CH_2NH-$, $-CH_2S-$, $-CH_2-CH_2-$, $-CH=CH-$ (cis and trans), $-COCH_2-$, $-CH(OH)CH_2-$, $-CH_2SO-$ and the like. (Morley (1980) *Trends Pharmacol. Sci.* 1: 463-468 (general review); Hudson *et al.* (1979) *Int. J. Pept. Protein Res.* 14: 177-185 ($-CH_2NH-$, CH_2CH_2-); Spatola *et al.* (1986) *Life Sci.* 38: 1243-1249 ($-CH_2-S$); Hann (1982) *J. Chem. Soc. Perkin Trans.* 1: 307-314 (-CH-CH-, *cis* and *trans*); Almquist *et al.* (1980) *J. Med. Chem.* 23: 1392-1398 ($-COCH_2-$); Jennings-White *et al.* (1982) *Tetrahedron Lett.* 23: 2533 ($-COCH_2-$); Holladay *et al.* (1983) *Tetrahedron Lett.* 24: 4401-4404 ($-C(OH)CH_2-$); and Hruby (1982) *Life Sci.* 31: 189-199 ($-CH_2S-$); each of which is incorporated herein by reference.).

Labeling of peptide mimetics usually involves covalent attachment of one or more labels, directly or through a spacer (*e.g.*, an amide group), to non-interfering position(s) on the peptide mimetic that are predicted by quantitative structure-activity data and molecular modeling. Such non-interfering positions generally are positions that do not form direct contacts with the macromolecule(s) (*e.g.*, in the present example they are not contact points in PAMP-PRR complexes) to which the peptide mimetic binds to produce the therapeutic effect. Derivitization (*e.g.*, labeling) of

peptide mimetics should not substantially interfere with the desired biological or pharmacological activity of the peptide mimetic.

PAMP peptide mimetics can be constructed by structure-based drug design through replacement of amino acids by organic moieties. (Hughes (1980) *Philos. Trans. R. Soc. Lond.* 290: 387-394; Hodgson (1991) *Biotechnol.* 9: 19-21; Suckling (1991) *Sci. Prog.* 75: 323-359).

The design of peptide mimetics can be aided by identifying amino acid mutations that increase or decrease binding of PAMP to its PRR. Approaches that can be used include the yeast two-hybrid method (Chien *et al.* (1991) *Proc. Natl. Acad. Sci. USA* 88: 9578-9582) and using the phage display method. The two-hybrid method detects protein-protein interactions in yeast. (Fields *et al.* (1989) *Nature* 340: 245-246). The phage display method detects the interaction between an immobilized protein and a protein that is expressed on the surface of phages such as lambda and M13. (Amberg *et al.* (1993) *Strategies* 6: 2-4; Hogrefe *et al.* (1993) *Gene* 128: 119-126). These methods allow positive and negative selection for protein-protein interactions and the identification of the sequences that determine these interactions.

Conventional methods of peptide synthesis are known in the art. (Jones (1992) Amino Acid and Peptide Synthesis, Oxford University Press; Jung (1997) Combinatorial Peptide and Nonpeptide Libraries: A Handbook, John Wiley; Bodanszky *et al.* (1993) Peptide Chemistry - A Practical Textbook, Springer Verlag).

E. Flagellin PAMPs

Bacterial flagella are made up of the structural protein Flagellin, which induces expression of chemokine IL-8 and activation of NF-κB in human and mouse

cells. Additionally Flagellin activates mammalian cells via a Toll-Like Receptor, TLR5. These findings, as well as the fact that Flagellin proteins are extremely conserved in bacteria, indicate that Flagellin is a pathogen-associated molecular pattern (PAMP) that would be recognized by the innate immune system.

Because Flagellin is a protein and a PAMP, it is also be suitable for the generation of recombinant fusion vaccines. As described in the Examples section below, a series of fusion constructs were tested for their ability to activate the mammalian innate immune system. Activation of NF-κB was used as a read-out in the experiments because it is a critical pathway indicative of the triggering of the Toll-Like Receptors, and has been demonstrated to be a property of the recombinant fusion vaccines.

F. Conservative Variants of PAMPs

The present invention also contemplates conservative variants of naturally-occurring protein PAMPs, peptides of PAMPs, and peptide mimetics of PAMPs that recognize the corresponding PRRs. Such variants are examples of PAMP mimetics. The conservative variations include mutations that substitute one amino acid for another within one of the following groups:

1. Small aliphatic, nonpolar or slightly polar residues: Ala, Ser, Thr, Pro and Gly;

2. Polar, negatively charged residues and their amides: Asp, Asn, Glu and Gln;

3. Polar, positively charged residues: His, Arg and Lys;

4. Large aliphatic, nonpolar residues: Met, Leu, Ile, Val and Cys; and

5. Aromatic residues: Phe, Tyr and Trp.

The types of substitutions selected may be based on the analysis of the frequencies of amino acid substitutions among the PAMPs of different species (Schulz *et al.* Principles of Protein Structure, Springer-Verlag, 1978, pp. 14-16) on the analyses of structure-forming potentials developed by Chou and Fasman (Chou *et al.* (1974) *Biochemistry* 13: 211; Schulz *et al.* (1978) Principles in Protein Structure, Springer-Verlag, pp. 108-130), and on the analysis of hydrophobicity patterns in proteins developed by Kyte and Doolittle (Kyte *et al.* (1982) *J. Mol. Biol.* 157: 105-132).

The present invention also contemplates conservative variants that do not affect the ability of the PAMP to bind to its PRR. The present invention includes PAMPs with altered overall charge, structure, hydrophobicity/hydrophilicity properties produced by amino acid substitution, insertion, or deletion that retain and/or improve the ability to bind to their receptor. Preferably, the mutated PAMP has at least about 70% sequence identity, more preferably at least about 80% sequence identity, even more preferably, at least about 85% sequence identity, yet more preferably at least about 90% sequence identity, and most preferably at least about 95% sequence identity to its corresponding wild-type PAMP.

Numerous methods for determining percent homology are known in the art. Version 6.0 of the GAP computer program is available from the University of Wisconsin Genetics Computer Group and utilizes the alignment method of Needleman and Wunsch, as revised by Smith and Waterman. (Needleman *et al.* (1970) *J. Mol. Biol.* 48: 443; Smith *et al.* (1981) *Adv. Appl. Math.* 2: 482). Numerous methods for determining percent identity are also known in the art, and a

preferred method is to use the FASTA computer program, which is also available from the University of Wisconsin Genetics Computer Group.

G. Combination Treatments

The present invention provides methods of treating subjects comprising passively immunizing an individual by administering antibodies or activated immune cells to a subject to confer immunity, and administering a vaccine comprising a fusion protein of the present invention, preferably wherein the administered antibody or activated immune cells are directed against the same antigen of the fusion protein of the vaccine. Such treatments can be sequential, in either order or simultaneous. This combination therapy contemplates the use of either monoclonal or polyclonal antibodies that are directed against the antigen of the PAMP/antigen fusion.

The present invention provides methods of treating subjects comprising passively immunizing an individual by administering antibodies or activated immune cells to a subject to confer immunity, and administering a vaccine comprising a chimeric construct of the present invention, wherein the administered antibody or activated immune cells are preferably directed against the same antigen of the chimeric construct. Such treatments can be sequential, in either order, or simultaneous. This combination therapy contemplates the use of either monoclonal or polyclonal antibodies that are directed against the antigen of the PAMP/antigen chimeric construct.

The present invention also contemplates the use of a vaccine comprising a chimeric construct of the present invention in combination with a second treatment where such second treatment is not an immune-directed therapy. A non-limiting

example of such combination therapy is the combination of a vaccine comprising a fusion protein of the present invention in combination with a chemotherapeutic agent, such as an anti-cancer chemotherapeutic agent. A further non-limiting example of such combination therapy is the combination of a vaccine comprising a fusion protein construct of the present invention in combination with an anti-angiogenic agent. A further non-limiting example of such combination therapy is the combination of a vaccine comprising a fusion protein of the present invention in combination with radiation therapy, such as an anti-cancer radiation therapy. Yet a further non-limiting example of combination therapy is the combination of a vaccine comprising a fusion protein of the present invention in combination with surgery, such as surgery to remove or reduce vascular blockage.

Also contemplated in this invention is a combination of more than one other therapeutic with a vaccine contemplated in this invention. A non-limiting example is a combination of a vaccine contemplated in this invention in combination with passive immunotherapy treatment and chemotherapy treatment.
In such combination treatments as can be contemplated herein, treatments can be sequential or simultaneous.

The PAMP domain can comprise the entire PAMP or an immunostimulatory portion of the PAMP. Preferably, the fusion protein has maximal immunogenicity and induces minimal inflammatory response. Such desirable properties might be achieved, for example, by using two or more different antigens, and/or portions of different antigens, and/or by using more than one copy of the same antigen or portions of the same antigen, and/or by a combination of both. Alternatively, two or more

different PAMPs, or portions of different PAMPs, and/or two or more copies of the same PAMP, or portions of the same PAMP, and/or a combination of both can be used. A further embodiment contemplates fusion proteins containing multiple antigens, and/or portions of antigens, together with multiple PAMPs, and/or portions of PAMPs. It is within the skill of the artisan to determine the desirable ratio of PAMP to antigen domains to maximize immunogenicity and minimize inflammatory response.

There are several advantages of using a fusion system for the production of recombinant polypeptides. First, heterologous proteins and peptides are often degraded by host proteases; this may be avoided, especially for small peptides, by using a gene fusion expression system. Second, general and efficient purification schemes are established for several fusion partners. The use of a fusion partner as an affinity handle allows rapid isolation and purification of the recombinant peptide. Third, by using different fusion partners, the recombinant product may be localized to different compartments or it might be secreted; such strategy could lead to facilitation of purification of the fusion partner and/or directed compartmentalization of the fusion protein.

Additionally, various methods are available for chemical or enzymatic cleavage of the fusion protein that provides efficient strategies to obtain the desired peptide in large quantities. Frequently employed fusion systems include: the *Staphylococcal* protein A fusion system and the synthetic ZZ variant, both of which have IgG affinity and have been used for the generation of antibodies against short peptides; the glutathione S-transferase fusion system (Smith *et al.* (1988) *Gene* 60);

the β-galactosidase fusion system; and the trpE fusion system (Yansura (1990) *Methods Enzym.* 185: 61). Some of these systems are commercially available as kits, including vectors, purification components and detailed instructions.

The present invention also contemplates modified fusion proteins having affinity for metal ion affinity matrices, whereby one or more specific metal-binding or metal-chelating amino acid residues are introduced, by addition, deletion, or substitution, into the fusion protein sequence as a tag. Optimally, a fusion partner, either an antigen or a PAMP domain, is modified to contain an added metal-chelating amino acid tag. The sequence of an antigen or PAMP domain, however, could also be altered to provide a metal-binding site if such modifications could be achieved without adversely affecting a ligand-binding site, an active site, or other functional sites, and/or destroying important tertiary structural relationships in the protein. These metal-binding or metal-chelating residues may be identical or different, and can be selected from the group consisting of cysteine, histidine, aspartate, tyrosine, tryptophan, lysine, and glutamate, and are located so to permit binding or chelation of the expressed fusion protein to a metal. Histidine is the preferred metal-binding residue. The metal-binding/chelating residues are situated with reference to the overall tertiary structure of the fusion protein to maximize binding/chelation to the metal and to minimize interference with the expression of the fusion protein its biological activity.

A fusion sequence of an antigen, PAMP and a tag, may optionally contain a linker peptide. The linker peptide might separate a tag from the antigen sequence or the PAMP sequence. If the linker peptide so used encodes a sequence that is

selectively cleavable or digestible by conventional chemical or enzymatic methods, then the tag can be separated from the rest of the fusion protein after purification. For example, the selected cleavage site within the tag may be an enzymatic cleavage site. Examples of suitable enzymatic cleavage sites include sites for cleavage by a proteolytic enzyme, such as enterokinase, Factor Xa, trypsin, collagenase, thrombin and the like. Alternatively, the cleavage site in the linker may be a site capable of cleavage upon exposure to a selected chemical or condition, *e.g.*, cyanogen bromide, hydroxylamine, or low pH, or other chemicals or conditions known in the art.

Cleavage at the selected cleavage site enables separation of the tag from the antigen/PAMP fusion protein. The antigen/PAMP fusion protein may then be obtained in purified form, free from any peptide derivative to which it was previously linked for ease of expression or purification. The cleavage site, if inserted into a linker useful in the fusion sequences of this invention, does not limit this invention. Any desired cleavage site, of which many are known in the art, may be used for this purpose.

Another use of linker peptides might be to direct cleavage of the antigen in intracellular processing so as to facilitate peptide presentation on the surface of the APC. Appropriate cleavage sites might be inserted via linkers such that the fusion protein is not cleaved until it is internalized by the APC. Under such circumstances, such a peptide cleavage site can be introduced via a linker between the PAMP and the antigen to generate intracellular antigen free of PAMP. Such directed cleavage could also be used particularly to facilitate production within the APC of specific peptides that have been identified as interacting with particular HLA haplotypes.

Alternatively, different domains from a single antigen or from more than one antigen might be separated by linkers containing cleavage sites so that these epitopes could be appropriately processed for presentation on the surface of the APC.

The optional linker peptide in a fusion protein of the present invention might serve a purpose other than the provision of a cleavage site. As an example, and not by limitation, the linker peptide might be inserted between a PAMP domain and an antigen domain to prevent or alleviate steric hindrance between the two domains. In addition, the linker sequence might provide for post-translational modification including, but not limited to, *e.g.*, phosphorylation sites, biotinylation sites, sulfation sites, carboxylation sites, glycosylation sites, lipidation sites, and the like.

In one embodiment, the fusion protein of this invention contains a domain of an antigen or an immunogenic portion of an antigen fused directly at its amino or carboxyl terminal end to the domain of a PAMP or an immunostimulatory portion of a PAMP. In another embodiment, the fusion protein of this invention contains a domain of a PAMP, or an immunostimulatory portion of a PAMP, or a sequence that can be post-translationally modified to produce a PAMP, inserted within the domain of an antigen, or an immunogenic portion of an antigen. In yet another embodiment, the fusion protein of this invention contains a domain of an antigen, or an immunogenic portion of an antigen, inserted within the domain of a PAMP, or an immunostimulatory portion of a PAMP, or a sequence that can be post-translationally modified to produce a PAMP. In another embodiment, the fusion protein of this invention, comprising an antigen and a PAMP sequence, is fused directly at its amino or carboxyl terminal end to the sequence of a tag. The resulting fusion protein is a

soluble cytoplasmic fusion protein. In another embodiment, the fusion sequence further comprises a linker sequence interposed between the antigen sequence and a PAMP sequence or sequence of a tag. This fusion protein is also produced as a soluble cytoplasmic protein.

H. Recombinant Technology

Protein PAMPs, protein antigens, and derivatives thereof can be generated using standard peptide synthesis technology. Alternatively, recombinant methods can be used to generate nucleic acid molecules that encode protein PAMPs, protein antigens and derivatives thereof.

Nucleic acids encoding PAMP/antigen fusions (*e.g.*, synthetic oligo- and polynucleotides) can easily be synthesized by chemical techniques, for example, the phosphotriester method of Matteucci, *et al.* ((1981) *J. Am. Chem. Soc.* 103: 3185-3191) or using automated synthesis methods. In addition, larger nucleic acids can readily be prepared by well known methods, such as synthesis of a group of oligonucleotides that define various modular segments of the nucleic acid encoding the PAMP/antigen fusion, followed by ligation of oligonucleotides to build the complete nucleic acid molecule.

The present invention further provides recombinant nucleic acid molecules that encode PAMP/antigen fusion proteins. As used herein, a "recombinant nucleic acid molecule" refers to a nucleic acid molecule that has been subjected to molecular manipulation *in vitro*. Methods for generating recombinant nucleic acid molecules are well known in the art. (Sambrook *et al.* (1989) Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Press). In the preferred recombinant nucleic acid

molecules, a nucleotide sequence that encodes a PAMP/antigen fusion is operably linked to one or more expression control sequences and/or vector sequences.

The choice of vector and/or expression control sequences to which one of the PAMP/antigen fusion encoding sequences of the present invention is operably linked depends directly, as is well known in the art, on the functional properties desired (*e.g.*, protein expression), and the host cell to be transformed. A vector contemplated by the present invention is at least capable of directing the replication or insertion into the host chromosome, and preferably also expression, of a nucleotide sequence encoding a PAMP/antigen fusion.

Expression control elements that are used for regulating the expression of an operably linked protein encoding sequence are known in the art and include, but are not limited to, inducible promoters, constitutive promoters, secretion signals, enhancers, transcription terminators and other regulatory elements. Preferably, an inducible promoter that is readily controlled, such as being responsive to a nutrient in the medium, is used.

In one embodiment, the vector containing a nucleic acid molecule encoding a PAMP/antigen fusion will include a prokaryotic replicon, *e.g.*, a nucleotide sequence having the ability to direct autonomous replication and maintenance of the recombinant nucleic acid molecule intrachromosomally in a prokaryotic host cell, such as a bacterial host cell, transformed therewith. Such replicons are well known in the art. In addition, vectors that include a prokaryotic replicon may also include a gene whose expression confers a detectable marker such as a drug resistance. Typical

bacterial drug resistance genes are those that confer resistance to ampicillin (Amp) or tetracycline (Tet).

Vectors that include a prokaryotic replicon can further include a prokaryotic or viral promoter capable of directing the expression (transcription and translation) of the PAMP/antigen fusion in a bacterial host cell, such as *E. coli*. A promoter is an expression control element formed by a nucleic acid sequence that permits binding of RNA polymerase and transcription to occur. Promoter sequences compatible with bacterial hosts are typically provided in plasmid vectors containing convenient restriction sites for insertion of a nucleic acid segment of the present invention. Typical of such vector plasmids are pUC8, pUC9, pBR322 and pBR329 available from Biorad Laboratories (Richmond, CA), pPL and pKK223 available from Amersham Pharmacia Biotech, Piscataway, NJ.

Expression vectors compatible with eukaryotic cells, preferably those compatible with vertebrate cells, can also be used to express nucleic acid molecules that contain a nucleotide sequence that encodes a PAMP/antigen fusion. Eukaryotic cell expression vectors are well known in the art and are available from several commercial sources. Typically, such vectors provide convenient restriction sites for insertion of the desired DNA segment. Typical of such vectors are pSVL and pKSV-10 (Amersham Pharmacia Biotech), pBPV-1/pML2d (International Biotechnologies, Inc.), pTDT1 (ATCC, #31255), the vector pCDM8 described herein, and other like eukaryotic expression vectors.

Eukaryotic cell expression vectors used to construct the recombinant molecules of the present invention may further include a selectable marker that is

effective in a eukaryotic cell, preferably a drug resistance selection marker. A preferred drug resistance marker is the gene whose expression results in neomycin resistance, *e.g.*, the neomycin phosphotransferase (*neo*) gene. (Southern *et al. (1982) J. Mol. Anal. Genet.* 1:327-341). Alternatively, the selectable marker can be present on a separate plasmid, and the two vectors are introduced by cotransfection of the host cell, and selected by culturing in the presence of the appropriate drug for the selectable marker.

The present invention further provides host cells transformed with a nucleic acid molecule that encodes a PAMP/antigen fusion protein of the present invention. The host cell can be either prokaryotic or eukaryotic. Eukaryotic cells useful for expression of a PAMP/antigen fusion protein are not limited, so long as the cell line is compatible with cell culture methods and compatible with the propagation of the expression vector and expression of the fusion protein. Preferred eukaryotic host cells include, but are not limited to, yeast, insect and mammalian cells, preferably vertebrate cells such as those from a mouse, rat, monkey or human fibroblastic cell line.

Any prokaryotic host can be used to express a recombinant nucleic acid molecule. The preferred prokaryotic host is *E. coli*. In embodiments where the PAMP is a lipoprotein, expression of the PAMP/antigen fusion protein in a bacterial cell is preferred. Expression of the nucleic acid in a bacterial cell line is desirable to ensure proper post-translational modification of the protein portion of the lipoprotein. Preferably, the host cells selected for expression of the PAMP/antigen fusion (*e.g.*

lipoprotein/antigen fusion) is the cell that natively produces the lipoprotein of the lipoprotein/antigen fusion.

Transformation of appropriate cell hosts with nucleic acid molecules encoding a PAMP/antigen fusion of the present invention is accomplished by well known methods that typically depend on the type of vector and host system employed. With regard to transformation of prokaryotic host cells, electroporation and salt treatment methods are typically employed. (*See e.g.,* Cohen *et al.* (1972) *Pro.c Natl. Acad. Sci. USA* 69:2110; Maniatis *et al.*, Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY (1982); Sambrook *et al.* (1989)). With regard to transformation of vertebrate cells with vectors containing rDNAs, electroporation, cationic lipid or salt treatment methods are typically employed. (*See e.g.,* Graham *et al.*, *Virology* (1973) 52:456; Wigler *et al.* (1979) *Proc. Natl. Acad. Sci. U.S.A.* 76:1373-76).

Successfully transformed cells, *e.g.*, cells that contain a nucleic acid molecule encoding the PAMP/antigen fusions of the present invention, can be identified by well known techniques. For example, cells resulting from the introduction of a nucleic acid molecule encoding the PAMP/antigen fusions of the present invention can be cloned to produce single colonies. Cells from those colonies can be harvested, lysed and their nucleic acids content examined for the presence of the recombinant molecule using a method such as that described by Southern (1975) (*J. Mol. Biol.* 98: 503), or Berent *et al.* (1985) (*Biotech.* 3: 208) or the proteins produced from the cell assayed via an immunological method.

The present invention further provides methods for producing a PAMP/antigen fusion protein that uses one of the nucleic acid molecules herein described. In general terms, the production of a recombinant protein typically involves the following steps.

First, a nucleic acid molecule is obtained that encodes a PAMP/antigen fusion protein. Said nucleic acid molecule is then preferably placed in an operable linkage with suitable control sequences, as described above. The expression unit is used to transform a suitable host and the transformed host is cultured under conditions that allow the production of the PAMP/antigen fusion protein. Optionally, the fusion protein is isolated from the medium or from the cells; recovery and purification of the fusion protein may not be necessary in some instances where some impurities may be tolerated.

Each of the foregoing steps can be done in a variety of ways. For example, the desired coding sequences may be obtained from genomic fragments and used directly in an appropriate host. The construction of expression vectors that are operable in a variety of hosts is accomplished using an appropriate combination of replicons and control sequences. The control sequences, expression vectors, and transformation methods are dependent on the type of host cell used to express the gene and were discussed in detail earlier. A skilled artisan can readily adapt any host/expression system known in the art for use with the nucleotide sequences described herein to produce a PAMP/antigen fusion protein.

Endonucleases are nucleases that are able to break internal phosphodiester bonds within a nucleic acid molecule. Examples of nucleases include, but are not

limited to, S1 endonuclease from the fungus *Aspergillus oryzae*, deoxyribonuclease (DNase I), and restriction endonucleases. The cutting and joining processes that underlie DNA manipulation are carried out by enzymes called restriction endonucleases (for cutting) and ligases (for joining). Suitable restriction endonuclease cleavage sites can, if not normally available, be added to the ends of the coding sequence so as to provide an excisable nucleic acid sequence to insert into these vectors.

In addition, restriction endonuclease cleavage sites may also be inserted in the nucleic acid sequence encoding the PAMP/antigen fusion protein. Preferably, these cleavage sites are engineered between nucleotide sequences encoding identical or different PAMPs; between identical or different antigens, or between nucleotide sequences encoding PAMP and antigen. Appropriate cleavage sites well know to those skilled in the art include, but are not limited to, the following: *Eco*RI, *Bam*HI, *Bgl*/II, *Pvu*I, *Pvu*II, *Hind*III, *Hinf*I, *Sau*3A, *Alu*I, *Taq*I, *Hae*III and *Not*I. (T.A. Brown (1996) Gene Cloning: An Introduction, Second Edition, Chapman & Hall, Chapter 4:49-83).

I. Conjugates

The present invention also includes "conjugates" which comprise two or more molecules that are covalently linked, or noncovalently linked but in association with each other. Thus, vaccines of the present invention include PAMP/antigen conjugates such as, but not limited to, the following: protein/nucleic acid conjugates, nucleic acid/protein conjugates, nucleic acid/nucleic acid conjugates, peptide-mimetic/nucleic acid conjugates, nucleic acid/peptide mimetic conjugates, peptide mimetic/peptide

mimetic conjugates, lipopolysaccharide/protein conjugates, lipoprotein/protein conjugates, RNA/protein conjugates, CpG-DNA/protein conjugates, nucleic acid analog/protein conjugates, and mannan/protein conjugates. To the extent that PAMPs identified in the future are comprised of yet other chemical classes, conjugates containing such chemicals in combination with antigen domains can also be contemplated.

Methods for the conjugation of polypeptides, carbohydrates, and lipids with DNA are well known to the artisan. *See e.g.,* U.S. Pat. Nos. 4,191,668, 4,650,625, 5,162,515, 5,700,922, 5,786,461, 6,06,0056; and J. *Clin. Invest.* (1988) 82:1901-1907.

Non-protein PAMPs such as CpG or CpG-DNA, and lipopolysaccharides may be conjugated to protein or non-protein antigens by conventional techniques. For example, PAMP/antigen conjugates may be linked through polymers such as PEG, poly-D-lysine, polyvinyl alcohol, polyvinylpyrollidone, immunoglobulins, and copolymers of D-lysine and D-glutamic acid. Conjugation of the PAMP and antigen to the polymer linker may be achieved in any number of ways, typically involving one or more crosslinking agents and functional groups on the PAMP and antigen. Polypeptide PAMPs and antigens will contain amino acid side chains such as amino, carbonyl, or sulfhydryl groups that will serve as sites for linking the PAMP and antigen to each other. Residues that have such functional groups may be added to either the PAMP or antigen. Such residues may be incorporated by solid phase synthesis techniques or recombinant techniques, both of which are well known in the peptide synthesis arts.

In the case of carbohydrate or lipid analogs, functional amino and sulfhydryl groups may be incorporated therein by conventional chemistry. For instance, primary amino groups may be incorporated by reaction with ethylenediamine in the presence of sodium cyanoborohydride and sulfhydryls may be introduced by reaction of cysteamine dihydrochloride followed by reduction with a standard disulfide reducing agent. In a similar fashion the polymer linker may also be derivatized to contain functional groups if it does not already possess appropriate functional groups. Heterobifunctional crosslinkers, such as sulfosuccinimidyl(4-iodoacetyl) aminobenzoate, which link the .epsilon. amino group on the D-lysine residues of copolymers of D-lysine and D-glutamate to a sulfhydryl side chain from an amino terminal cysteine residue on the peptide to be coupled, are also useful to increase the ratio PAMPs or antigens in the conjugate.

J. Vaccine Formulation and Delivery

The vaccines of the present invention contain one or more PAMPs, immunostimulatory portions, or immunostimulatory derivatives thereof (*e.g.*, a domain recognized by the innate immune system), and one or more antigens, immunogenic portions, or immunogenic derivatives thereof (*e.g.*, a domain recognized by the adaptive immune system). Since a PAMP mimetic, by definition, has the ability to bind PRRs and initiate an innate immune response, vaccine formulations contemplated by this invention include PAMP mimetics in place of PAMPs. Thus, the present invention contemplates vaccines comprising chimeric constructs including at least one antigen domain and at least one PAMP domain. In

one specific embodiment, the vaccines of the present invention comprise a BLP/Eα fusion protein.

The vaccines, comprising the chimeric constructs of the present invention, can be formulated according to known methods for preparing pharmaceutically useful compositions, whereby the chimeric constructs are combined in a mixture with a pharmaceutically acceptable carrier. A composition is said to be a "pharmaceutically acceptable carrier" if its administration can be tolerated by the recipient and if that composition renders the active ingredient(s) accessible at the site where the action is required. Sterile phosphate-buffered saline is one example of a pharmaceutically acceptable carrier. Other suitable carriers are well-known to those in the art. (Ansel *et al.*, Pharmaceutical Dosage Forms and Drug Delivery Systems, 5th Edition (Lea & Febiger 1990); Gennaro (ed.), Remington's Pharmaceutical Sciences 18th Edition (Mack Publishing Company 1990)).

Examples of several other excipients that can be contemplated may include, water, dextrose, glycerol, ethanol, and combinations thereof. The vaccines of the present invention may further contain auxiliary substances, such as wetting or emulsifying agents, pH buffering agents, stabilizers or other carriers that include, but are not limited to, agents such as aluminum hydroxide or phosphate (alum), commonly used as a 0.05 to 0.1 percent solution in phosphate buffered saline, to enhance the effectiveness thereof.

The chimeric constructs of the present invention can be used as vaccines by conjugating to soluble immunogenic carrier molecules. Suitable carrier molecules include protein, including keyhole limpet hemocyanin, which is a preferred carrier

protein. The chimeric construct can be conjugated to the carrier molecule using standard methods. (Hancock *et al.*, "Synthesis of Peptides for Use as Immunogens," in Methods in Molecular Biology: Immunochemical Protocols, Manson (ed.), pages 23-32 (Humana Press 1992)).

Furthermore, the present invention contemplates a vaccine composition comprising a pharmaceutically acceptable injectable vehicle. The vaccines of the present invention may be administered in conventional vehicles with or without other standard carriers, in the form of injectable solutions or suspensions. The added carriers might be selected from agents that elevate total immune response in the course of the immunization procedure.

Liposomes have been suggested as suitable carriers. The insoluble salts of aluminum, that is aluminum phosphate or aluminum hydroxide, have been utilized as carriers in routine clinical applications in humans. Polynucleotides and polyelectrolytes and water soluble carriers such as muramyl dipeptides have been used.

Preparation of injectable vaccines of the present invention, includes mixing the chimeric construct with muramyl dipeptides or other carriers. The resultant mixture may be emulsified in a mannide monooleate/squalene or squalane vehicle. Four parts by volume of squalene and/or squalane are used per part by volume of mannide monooleate. Methods of formulating vaccine compositions are well-known to those of ordinary skill in the art. (Rola, Immunizing Agents and Diagnostic Skin Antigens. In: Remington's Pharmaceutical Sciences,18th Edition, Gennaro (ed.), (Mack Publishing Company 1990) pages 1389-1404).

Additional pharmaceutical carriers may be employed to control the duration of action of a vaccine in a therapeutic application. Control release preparations can be prepared through the use of polymers to complex or adsorb chimeric construct. For example, biocompatible polymers include matrices of poly(ethylene-co-vinyl acetate) and matrices of a polyanhydride copolymer of a stearic acid dimer and sebacic acid. (Sherwood *et al.* (1992) *Bio/Technology* 10: 1446). The rate of release of the chimeric construct from such a matrix depends upon the molecular weight of the construct, the amount of the construct within the matrix, and the size of dispersed particles. (Saltzman *et al.* (1989) *Biophys. J.* 55: 163; Sherwood *et al., supra.*; Ansel *et al.* Pharmaceutical Dosage Forms and Drug Delivery Systems, 5th Edition (Lea & Febiger 1990); and Gennaro (ed.), Remington's Pharmaceutical Sciences, 18th Edition (Mack Publishing Company 1990)). The chimeric construct can also be conjugated to polyethylene glycol (PEG) to improve stability and extend bioavailability times (*e.g.*, Katre et al.; U.S. Patent 4,766,106).

The vaccines of this invention may be administered parenterally. The usual modes of administration of the vaccine are intramuscular, sub-cutaneous, and intra-peritoneal injections. Moreover, the administration may be by continuous infusion or by single or multiple boluses.

The gene gun has also been used to successfully deliver plasmid DNA for inducing immunity against an intracellular pathogen for which protection primarily depends on type 1 CD8.sup. + T-cells. (Kaufmann *et al.* (1999) *J. Immun.* 163(8): 4510-4518).

Gene transfer-mediated vaccination methods have become a rapidly expanding field and the compositions of the present invention are applicable to the treatment of both noninfectious and infectious diseases and noninfectious diseases, including but not limited to genetic disorders, using such vaccination methods. (See *e.g., Eck et al.* (1996) Gene-Based Therapy, In: Goodman & Gilman's The Pharmacological Basis of Therapeutics, Ninth Edition, Chapter 5, McGraw Hill).

Alternatively, the vaccine of the present invention, particularly as regards use of Flagellin as a PAMP, may be formulated and delivered in a manner designed to evoke an immune response at a mucosal surface. Thus, the vaccine compositions may be administered to mucosal surfaces by, for example, nasal or oral (intragastric) routes. Other modes of administration include suppositories and oral formulations. For suppositories, binders and carriers may include polyalkalene glycols or triglycerides. Oral formulations may include normally employed incipients such as pharmaceutical grades of saccharine, cellulose and magnesium carbonate. These compositions can take the form of solutions, suspensions, tablets, pills, capsules, sustained release formulations or powders and contain about 1 to 95% of the chimeric construct. The vaccines are administered in a manner compatible with the dosage formulation, and in such amount as will be therapeutically effective, protective and immunogenic dosages.

The quantity of vaccine employed will of course vary depending upon the patient's age, weight, height, sex, general medical condition, previous medical history, the condition being treated and its severity, and the capacity of the individual's immune system to synthesize antibodies, and produce a cell-mediated immune

response. Typically, it is desirable to provide the recipient with a dosage of the chimeric construct which is in the range of from about 1 μg agent /kg body weight of patient to 100 mg agent/kg body weight of patient, although a lower or higher dosage may also be administered. Precise quantities of the active ingredient, however, depend on the judgment of the practitioner. Suitable dosage ranges are readily determinable by one skilled in the art and may be on the order of nanograms of the chimeric construct to grams of the chimeric construct, depending on the particular construct. Preferably the dosage range of the active ingredient is nanograms to micrograms; more preferably nanograms to milligrams; and most preferably micrograms to milligrams. Suitable regimes for initial administration and booster doses are also variable, but may include an initial administration followed by subsequent administrations. The dosage may depend on the route of administration and will vary according to the size of the subject.

The present invention encompasses vaccines containing antigen and PAMPs from a single organism, such as from a specific pathogen. The present invention also encompasses vaccines that contain antigenic material from several different sources and/or PAMP material isolated from several different sources. Such combined vaccines contain, for example, antigen and PAMPs from various microorganisms or from various strains of the same microorganism, or from combinations of various microorganisms.

For purposes of therapy, the antigen/PAMP fusion proteins are administered to a mammal in a therapeutically effective amount. A vaccine preparation is said to be administered in a "therapeutically effective amount" if the amount administered is can

produce a measurable positive effect in a recipient. In particular, a vaccine preparation of the present invention produces a positive effect in a recipient if it invokes a measurable humoral and/or cellular immune response in the recipient. In particular, this invention contemplates a desirable therapeutically effective amount as one in which the vaccine invokes in the recipient a measurable humoral and/or cellular immune response versus the target antigen but causes neither excessive non-specific inflammation nor an autoimmune response versus non-target antigen(s).

As used herein, the term "treatment" refers to both therapeutic treatment and prophylactic or preventative treatment. In one embodiment, the present invention contemplates using the disclosed vaccines to treat patients in need thereof. The patients may be suffering from diseases such as, but not limited to, cancer, allergy, infectious disease, autoimmune disease, neurological disease, cardiovascular disease, or a disease associated with an allergic reaction. In another embodiment, the present invention contemplates administering the disclosed vaccines to passively immunize patients against diseases such as but not limited to, cancer, allergy, infectious disease, autoimmune disease, neurological disease, cardiovascular disease, or disease associated with an allergic reaction. In yet another embodiment the present invention contemplates administering the disclosed vaccines to immunize patients against diseases in addition to those cited in the previous sentence in which the objective is to rid the body of specific molecules or specific cells. A non-limiting example might be the removal or prevention of deposition of plaque in cardiovascular disease.

K. Treatment/Enhancement of Immunity

The vaccines of the present invention can be used to enhance the immunity of animals, more specifically mammals, and even more specifically humans (*e.g.*, patients) in need thereof. Enhancement of immunity is a desirable goal in the treatment of patients diagnosed with, for example, cancer, immune deficiency syndrome, certain topical and systemic infections, leprosy, tuberculosis, shingles, warts, herpes, malaria, gingivitis, and atherosclerosis.

The advantages of the vaccines of the present invention are that they induce a strong immune response against the target antigen with minimal undesired inflammatory reaction, as well as minimal instances of autoimmune disease. Such a reduced side effect profile has a distinct advantage over other vaccine approaches, particularly with respect to targeting of self antigens, because with many other vaccine strategies, in order to elicit a robust response against the self antigen, strong adjuvants are used and they result in excessive inflammation and can increase the risk of autoimmune disease.

As used herein, "immunoenhancement" refers to any increase in an organism's capacity to respond to foreign antigens or other targeted antigens, such as those associated with cancer, which includes an increased number of immune cells, increased activity and increased ability to detect and destroy such antigens, in those cells primed to attack such antigens.

The strength of an immune response can be measured by standard tests including, but not limited to, the following: direct measurement of peripheral blood lymphocytes by means known to the art; natural killer cell cytotoxicity assays (Provinciali *et al.* (1992) *J. Immunol. Meth.* 155: 19-24), cell proliferation assays

(Vollenweider *et al.* (1992) *J. Immunol. Meth.* 149: 133-135), immunoassays of immune cells and subsets (Loeffler *et al.* (1992) *Cytom.* 13: 169-174; Rivoltini *et al.* (1992) *Can. Immunol. Immunother.* 34: 241-251); and skin tests for cell- mediated immunity (Chang *et al.* (1993) *Cancer Res.* 53: 1043-1050). For an excellent text on methods and analyses for measuring the strength of the immune system, see, for example, Coligan *et al.* (Ed.) (2000) *Current Protocals in Immunology*, Vol. 1, Wiley & Sons.

Any statistically significant increase in the strength of immune response, as measured by the above tests, is considered "enhanced immune response" or "immunoenhancement". An increase in T-cells in S-phase of greater than 5 percent has been achieved by the methods of this invention. Enhanced immune response is also indicated by physical manifestations such as fever and inflammation, although one or both of these manifestations might not be observed with the recombinant vaccines of the present invention. Enhanced immune response is also characterized by healing of systemic and local infections, and reduction of symptoms in disease, *e.g.* decrease in tumor size, alleviation of symptoms of leprosy, tuberculosis, malaria, naphthous ulcers, herpetic and papillomatous warts, gingivitis, atherosclerosis, the concomitants of AIDS such as Kaposi's sarcoma, bronchial infections, and the like.

L. Vaccine Production

The procedures of the present invention can be used to generate a chimeric construct comprising one or more antigens of interest and one or more PAMPs. A small, non-immunogenic epitope tag (such as a His tag) can be added to facilitate the purification of fusion protein expressed in bacteria. The combination of antigen with

a PAMP such as BLP or Flagellin provides signals necessary for the activation of the antigen-specific adaptive and innate immune responses.

A large number of differing fusion proteins comprising different combinations of antigens and PAMPs can be readily generated using recombinant DNA technology or conjugation chemistry that is well known in the art. Virtually any antigen can be used to generate a vaccine by this approach using the same technology. This novel approach, therefore, is very versatile.

Large amounts of recombinant vaccine product can be generated using a bacterial expression system. The product can be purified from bacterial cultures using standard techniques. The approach is thus extremely economical and cost efficient. Alternatively, recombinant vaccine product can be produced and purified from cultures of yeast or other eukaryotic cells including, without limitation, insect cells or mammalian cells. Conjugated non-protein vaccine product can also be produced chemically in relatively large amounts. This is particularly the case if the PAMP and the antigen can both be obtained by relatively straightforward purification procedures and then conjugated together with relatively simple and efficient conjugation chemistry.

Alternatively, a chimeric construct containing a protein component and a non-protein component can be conveniently obtained by preparing the protein component by recombinant means and the non-protein component by chemical means and then linking the two components with linker chemistry well known in the art, some of which is described herein. Additionally, since the antigens and PAMPs contemplated in this invention can be naturally occurring, they can be purified from their natural

sources and then linked together chemically. Both T-cell and B-cell antigens can be used to generate vaccines by this approach.

Fusion of an antigen with a PAMP such as BLP or Flagellin optimizes the stoichiometry of the two signals thus minimizing the unwanted excessive inflammatory responses (which occur, for example, when antigens are mixed with adjuvants to increase their immunogenicity).

Fusion of an antigen with a PAMP such as BLP increases the likelihood that APCs activated in response to the vaccine productively trigger the desired adaptive immune response. Activation of such APCs in the absence of uptake and presentation of the antigen can lead to the induction of autoimmune responses, which, again, is one of the problems with commonly used adjuvants that prevents or limits their use in humans.

In a preferred embodiment, the fusion proteins of the present invention comprise an antigen or an immunogenic portion thereof which has been modified to contain an amino acid sequence comprising a leader sequence and a consensus sequence, that results in the post-translational modification of the consensus sequence or a portion of that sequence, wherein the post-translationally modified sequence is a ligand for a PRR. The modified antigens include, but are not limited to, antigens that contain the bacterial lipidation consensus sequence CXXN (SEQ ID NO: 1), wherein X is any amino acid, but preferably serine. Numerous leader sequences are well known in the art, but a preferred leader sequence is described by the first 20 amino acids of SEQ ID NO: 2, wherein the first 20 amino acids of SEQ ID NO: 2 are set forth in set forth in SEQ ID NO: 3. Examples of additional suitable leader sequences

are described in the Sequence Listing as SEQ ID NO: 4-7. A preferred chimeric construct comprises a leader sequence fused, in frame, to a sequence comprising the bacterial lipidation consensus sequence of SEQ ID NO: 1 further fused to an antigen (*e.g.* leader sequence—CXXN—antigen). Although this modification of the antigen can be referred to as a fusion, this modification can be achieved without fusing DNA, but rather by introducing, by mutagenesis, a leader sequence followed by the CXX sequence into DNA encoding any antigen of interest. Expression of a nucleic acid molecule encoding this chimeric construct, in a bacterial host cell, produces a substrate, first for bacterial proteases, that cleave the leader sequence from the modified antigen, and bacterial lipid transferases, which lipidate the sequence, or a portion thereof, comprising the lipidation consensus sequence. The resultant product is a chimeric construct or fusion protein that is a ligand for a PRR and is capable of stimulating both the innate and adaptive immune systems. In an additional embodiment, this chimeric construct or fusion protein comprises additional polar or charged amino acids to increase the hydrophilicity of the chimeric construct or fusion protein without altering the immunogenic or immunostimulatory properties of the construct.

Without further description, it is believed that one of ordinary skill in the art can, using the preceding description and the following illustrative examples, practice the methods of the present invention. The following working examples, therefore, specifically point out the preferred embodiments of the present invention, are illustrative only, and are not to be construed as limiting in any way the remainder of

the disclosure. Other generic and specific configurations will be apparent to those persons skilled in the art.

EXAMPLES

Example 1. Model Vaccine Cassette with an Antigen Domain and a PAMP Domain

In order to produce a model vaccine cassette of the present invention, we fused a pathogen-associated molecular pattern (PAMP) to the characterized mouse antigen, Eα. The PAMP we selected, BLP, is known to stimulate innate immune responses through the receptor, Toll-like-receptor-2 (TLR-2).

The protein sequence of the bacterial lipoprotein (BLP) used in the vaccine cassette for fusion with an antigen of interest is as follows: MKATKLVLGAVILGSTLLAGCSSNAKIDQLSSDVQTLNAKVDQLSNDVNAM RSDVQAAKDDAARANQRLDNMATKYRK (SEQ ID NO: 2). The leader sequence includes amino acid number 1 through amino acid number 20 of SEQ ID NO: 2. The first cysteine (amino acid number 21 of SEQ ID NO: 2) is lipidated in bacteria. This lipidation, which can only occur in bacteria, is essential for BLP recognition by Toll and TLRs. The C-terminal lysine (amino acid number 78 of SEQ ID NO: 2) was mutated to increase the yield of a recombinant vaccine, because this lysine can form a covalent bond with the peptidoglycan.

To assist in identification and purification of the antigen, a hexa-histidine tag was engineered on the C-terminal of the protein. The final construct is shown in Figure 3.

The fusion protein was expressed in bacteria and induced with IPTG. The protein was purified by lysis and sonication in 8 M Urea, 20 mM Tris, 20 mM NaCl, 2% Triton-X-100, pH 8.0. The lysate was passed over a 100 ml Q-Sepharose ion exchange column in the same buffer and washed with 5 column volumes of 8 M Urea, 20 mM Tris, 20 mM NaCl, 0.2% Triton-X-100, pH 8.0. The protein was eluted by salt gradient (20 mM NaCl to 800 mM NaCl). Positive fractions were identified by immunoblotting using an antibody to the Histidine tag. These fractions were pooled and passed over a 2 ml nickel-agarose column. The column was extensively washed with the same buffer (10 column volumes) and then washed with 5 column volumes of phosphate buffer (20 mM) containing 200 mM NaCl, 0.2% Triton-X-100, 20 mM imidazole, pH 8.0. The purified protein was eluted in 20 mM phosphate buffer, 200 mM NaCl, 0.1% Triton-X-100, 250 mM imidazole and fractions were again tested for protein by immunoblotting. Positive fractions were pooled and dialyzed overnight against phosphate buffered saline containing 0.1% Triton-X-100. The sample was then decontaminated of any endotoxin by passage over a polymyxin B column, and concentrated in an Amicon concentrator by centrifugation and tested by immunoblotting and protein concentration for protein content.

Example 2. Stimulation of NF-κB by BLP/Eα model antigen in RAW cells

To test whether the model antigen could stimulate signal transduction pathways necessary for an immune response, we assayed NF-κB activation in the RAW mouse macrophage cell line *in vitro*. We developed a stable RAW cell line that harbors an NF-κB-dependent firefly luciferase gene. Stimulation of these cells with activators of NF-κB leads to production of luciferase which is measured in cell lysates

by use of a luminometer. Cells were stimulated with the indicated amounts of BLP/Eα left 5 hours and harvested for luciferase measurement.

As a control, RAW cells were stimulated with LPS in the presence and absence of polymyxin B (PmB). PmB inactivates endotoxin and as expected the activation of NF-κB activity in the LPS+PmB sample is diminished by 98%. BLP/Eα also activates NF-κB in a dose-dependent manner as shown in Figure 4, however, treatment with PmB does not inactivate the stimulus to a statistically significant degree. These results suggest that the activation of NF-κB seen with BLP/Eα is not due to contamination of the preparation with endotoxin.

Example 3. BLP/Eα Model Vaccine Induces the Production of IL-6 by Dendritic Cells *In Vitro*

An effective vaccine must be able to stimulate dendritic cells (DC)to mature and present antigen. To test whether BLP/Eα could induce DC function, we tested the ability of bone marrow-derived DC to produce IL-6 after stimulation in vitro. Bone marrow dendritic cells were isolated and grown for 5 days in culture in the presence of 1% GM-CSF. After 5 days, cells were replated at 250,000 cells/well in a 96-well dish and treated with either Eα peptide (0.3μg/ml), LPS (100ng/ml) + Eα peptide (0.3μg/ml), or BLP/Eα. BLP/Eα was able to stimulate IL-6 production in these cells as measured in a sandwich ELISA (Figure 5).

Example 4. BLP/Eα Stimulates Maturation of Immature Dendritic Cells

To determine whether BLP/Eα vaccine can be processed and presented by dendritic cells, we stimulated dendritic cells with the vaccine and tested them for the surface expression of B7.2 and Eα peptide bound to MHC Class II. Cultured bone

marrow-derived dendritic cells (5 days) were stimulated with Eα peptide or BLP/Eα and were stained with an antibody to the B7.2 costimulatory molecule and/or with Yae antibody which recognizes Eα peptide bound to MHC Class II. Analysis was performed by FACS (Figure 6).

Example 5. BLP/Eα Model Vaccine Stimulates Specific T-Cells In Vitro

We next assayed whether BLP/Eα that was processed and presented by DC could stimulate the proliferation of antigen-specific T-cells in vitro. Bone marrow derived mouse DC were isolated and plated into medium containing 1% GM-CSF at 750,000 cells/well. Cells were cultured for 6 days and then the DC were collected, washed, and counted then replated in 96-well dishes at 250,000 cells per well. Cells were stimulated with the above indicated antigens and left three days to mature. After 3 days, the DC were resuspended and plated in a 96-well dish at either 5,000 or 10,000 cells/well. T-cells from lymph nodes from a 1H3.1 TCR transgenic mouse (1H3.1 TCR is specific for the Eα peptide)were plated on the DC at 100,000 cells/well. Cells were left for 3 days in culture then "pulsed" with 0.5μCi/well of ^{3}H-thymidine. The cells were harvested 24 hours later and incorporation of thymidine (T-cell proliferation) was measured in cpm (Figure 7).

Example 6. BLP/Eα Activates Specific T-cells In Vivo

To assess the ability of the vaccine to generate a specific T-cell response in vivo, we injected the fusion protein into a mouse. Three mice were injected as follows:

Mouse #	Sample injected	# of lymph node cells
1	Eα peptide 30μg in PBS	$1.9x10^6$
2	Eα peptide 30μg in CFA*	$3.29x10^7$
3	BLP/ Eα 100μg	$5.2x10^6$

*Complete Freund's Adjuvant

The injected footpad of mouse #2 was considerably swollen for the duration of the experiment, but the footpads of mice #1 and #3 appeared normal. After 6 days, the mice were euthanized and the associated draining lymph node was harvested for a T-cell proliferation assay. T-cells were plated in a 96-well plate at 400,000 cells/well and were restimulated with either Eα peptide or with BLP/Eα at the indicated doses. Cells were left 48 hours to begin proliferation, pulsed with 0.5μCi/well of ^{3}H-Thymidine in medium and harvested 16 hours later. Thymidine incorporation was measured by counting in a beta-plate reader (Figure 8).

Example 7. Model Vaccine Cassette with an Allergen-Related Antigen

Using the procedures set forth above for the production of the BLP/Eα model antigen, a vaccine cassette with an allergen-related antigen is produced using the pollen allergen Ra5G from the giant ragweed (*Ambrosia trifida*). The amino acid sequence of Ra5G is as follows:

MKNIFMLTLF ILIITSTIKA IGSTNEVDEI KQEDDGLCYE GTNCGKVGKY CCSPIGKYCVCYDSKAICNK NCT (SEQ ID NO: 9).

The amino acid sequence of this allergen can be fused with the BLP amino acid sequence (SEQ ID NO: 1) to generate the BLP/Ra5G fusion protein. The resultant recombinant vaccine places the allergen in the context of an IL-12 inducing signal, where the PAMP in this case is BLP).

When introduced into a subject, this vaccine will generate allergen-specific T-cell responses that will be differentiated into Th1 responses due to the induction of IL-12 by BLP in dendritic cells and macrophages.

Example 8. Model Vaccine Cassette with a Tumor-Related Antigen

Using the procedures set forth above for the production of the BLP/Eα model antigen, a vaccine cassette with a tumor-related antigen is produced using the model tumor antigen, Tyrosinase-Related Protein 2 (TRP-2). The nucleic acid sequence and corresponding amino acid sequence of TRP-2 is provided in SEQ ID NO: 10 (shown in Figure 20) and SEQ ID NO: 11 (shown in Figure 21), respectively. The region used for BLP fusion includes nucleic acid number 840 through nucleic acid number 1040 of SEQ ID NO: 10. The T-cell epitope includes nucleic acid number 945 through nucleic acid number 968 of SEQ ID NO: 10.

A region of the TRP-2 that can be used for the vaccine construction is shown below:

LDLAKKSIHPDYVITTQHWLGLLGPNGTQPQIANCSVYDFFVWLHYYS VRDTLLGPGRPYKAIDFSHQ (SEQ ID NO: 12).

A T-cell epitope of SEQ ID NO: 12 is VYDFFVWL (SEQ ID NO: 13).

Example 9: CpG Immunostimulation

The family of TLRs has recently been identified as an essential component of innate immune recognition in both *Drosophila* and mammalian organisms (Hoffmann *et al.* (1999) Science 284:1313-1318; Imler *et al.* (2000) *Curr. Opin. Microbiol.* 3:16-22). *Drosophila* Toll is required for the detection of fungal infection and the induction of the antifungal peptide drosomycin (Lemaitre *et al.* (1996) *Cell* 86:973-983). In the mouse, TLR2 and TLR4 were shown to mediate recognition of bacterial PGN and LPS, respectively (Takeuchi *et al.* (1999) *Immunity* 11:443-451). The functions of the other members of the *Drosophila* and mammalian Toll families are currently unknown, although it is expected that at least some of them are involved in innate immune recognition as well.

Collectively, the results described here indicate that the immunostimulatory effect of CpG-DNA on the three types of professional antigen presenting cells- DC, macrophages and B-cells -- is mediated by a MyD88 signaling pathway. MyD88 is involved in signal transduction by the Toll and IL-1 receptor families. The activities of the IL-1 family of cytokines, including IL-1 and IL-18, is dependent on processing by caspase-1, but in all the experiments described here, the absence of caspase-1 had no effect on CpG-DNA induced cellular responses (Fantuzzi *et al.* (1999) *J. Clin. Immunol.* 19:1-11).

We tested whether TLR2 and TLR4 are involved in the recognition of CpG-DNA and found that they are not, at least based on the assays provided herein. We believe, therefore, that CpG-DNA is recognized by a Toll receptor other than TLR2 and TLR4. Cell lines that express endogenous or transfected TLR1 through TLR6 did

not respond to CpG-DNA (data not shown), suggesting that some other member of the Toll family may mediate CpG-DNA recognition.

While the identity of the Toll receptor that is responsible for CpG-DNA recognition remains unknown at this point, the fact that CpG-DNA requires internalization to exert its stimulatory effect (Krieg *et al.* (1995) *Nature* 374:546-549; Stacey *et al.* (1996) *J. Immunol.* 157:2116-2122) suggests that the TLR that mediates the recognition may be expressed in an intracellular compartment, such as the late endosome, phagosome, or lysosome.

Example 10. CpG and B-Cell Activation

B-cells from the indicated mouse strains were purified from spleen by complement kill of $CD4^+$, $CD8^+$ and macrophages. Non-adherent cells were cultured in the presence or absence of different amounts of stimulating CpG-DNA (5'-TCCATGACGTTCCTGACGTT-3' (SEQ ID NO. 8), phosphorothioate modified) at 1×10^6 cells/ml. After 48 h, the cells were pulsed with [^{3}H]thymidine (0.5μCi per well, NEN) for 16 h and processed for beta counting.

Results shown in Figure 9A are representative of three independent experiments. B-lymphocytes derived from caspase-1 knock-out mice proliferated in response to CpG comparably to wild type cells (Figure 9A), suggesting that the effect of the MyD88 deletion is not due to a defect in IL-1/IL-18 mediated signaling. This result indicates that CpG-DNA signals through the receptors of the Toll family. B-cells from two available TLR-deficient mouse strains, the C57BL/10ScCr strain that carries a spontaneous deletion of the TLR4 gene (Poltorak *et al.* (1998) *Science* 282:2085-2088; Qureshi *et al. J. Exp. Med.*1999, 189:615-625) and TLR2 knock-out

mouse (Takeuchi *et al.* (1999) *Immunity* 11:443-451), both proliferated in response to CpG similar to the wild-type cells (Figure 9A). This result, together with the normal responses of the caspase-1 deficient cells, suggested that a member(s) of the Toll family other than TLR2 or TLR4 is involved in recognition of CpG-DNA.

Example 11. CpG and B-cell Expression of CD86 and MHC class II

The CpG-induced expression of CD86 and upregulation of MHC class-II molecules on B-cells was tested to determine whether these processes are mediated by the MyD88 signaling pathway. B-lymphocytes from MyD88 knock-out mice and wild-type littermate control mice, as well as those from TLR4-deficient mice, were stimulated by CpG-DNA. CD86 and MHC class -II cell surface expression were analyzed by FACS.

B-cells were prepared as above and cultured at 3 x 10^6 cells/ml with or without 10 mM CpG for 12 h. After the stimulation, the surface expression of CD86 and MHC class II were analyzed by flow cytometry. Results, shown in Figure 9B, represent gated B-cells. The shaded area represents stimulated cells, whereas the unshaded area represents untreated controls. As shown in Figure 9B, CpG-DNA strongly induced expression of CD86 and MHC class-II on B-cells from wild-type and TLR4-deficient mice. By contrast, this induction was completely abrogated in MyD88 deficient B-lymphocytes.

Example 12. Cloning of Salmonella Tymphimurium Flagellin and E. coli Flagellin

Full-length *Salmonella typhimurium* Flagellin and *E coli* Flagellin were cloned from the respective genomic DNAs and expressed as recombinant proteins in *E coli* . Flagellin was expressed alone, or as a fusion protein with antigenic epitopes from ovalbumin (SIINFEKL), tyrosinase-2 protein (TRP2) cloned from murine B16 cells, or the C-terminal fragment of I-Eα protein, which contains the Eα epitope. In addition, all of the recombinant proteins contained a C-terminal 6x-histidine repeat to aid in purification.

Induced bacteria were lysed in a gentle lysis buffer containing Triton-X 100, glycerol, imidazole, NaCl, and Tris, pH=8.0 to maintain the native conformation of the proteins. Fusion proteins were purified by passing filtered lysates over a Nickel-NTA agarose column followed by extensive washes in several buffers containing imidazole. Purified proteins were eluted in 250mM imidazole, passed twice over a Polymyxin B column to remove contaminating lipopolysaccharide and then dialyzed extensively overnight in PBS at 4°C. The resulting purified proteins were very stable and retain activity at 4°C for at least a month.

Example 13. Flagellin In vitro Assays

In vitro assays were performed using purified Flagellin fusion proteins as follows:

The human 293 cell line and the murine RAW cell line were stably transfected with a reporter gene containing two copies of the Igκ NF-κB site driving transcription

of luciferase (this construct is referred to as "pBIIxluc"). The resulting cell lines (293LUC and RAWkb) were plated in 24-well dishes and treated 24 hours later with Flagellin fusion proteins or a control protein (lacZ) that was made in the same vector and purified exactly the same way as the Flagellin proteins. Cell lysates were made after 5 hours of treatment and were tested for luciferase activity to indicate induction of NF-κB. The Flagellin proteins significantly induced NF-κB in this assay, particularly in 293 cells whereas the control protein had no effect, as shown in Figures 12 and 13. It is believed that this induction was not due to contamination by LPS since polymyxin B did not inhibit the activation in RAWκB cells, and 293LUC cells do not respond to LPS but do respond to Flagellin, as indicated by Figures 12 and 14.

The results of the In vitro assays demonstrate that Flagellin fusion proteins retain their ability to stimulate Toll-Like Receptors and can therefore be used for the generation of recombinant Flagellin-Antigen fusion proteins for the purpose of vaccination. In Flagellin-Antigen fusion proteins, Flagellin is believed to stimulate the innate immune system by triggering Toll-Like Receptors, whereas the antigen fused to Flagellin provides epitopes for recognition by T and B lymphocytes.

Example 14: CpG and IL-6 Production in Macrophages

Adherent thioglycollate-elicited peritoneal exudate cells (PECs) from the indicated mouse strains were treated with different stimuli for 24 h. The release of IL-6 into the supernatant was analyzed by specific enzyme-linked immunosorbent assay (ELISA) using anti-mouse IL-6 monoclonal antibodies. As CpG-DNA is also known to have a pronounced stimulatory effect on macrophages (Stacey *et al.* (2000) *Curr. Top. Microbiol. Immunol.* 247: 41-58; Lipford *et al.* (1998) *Trends Microbiol.* 6: 496-

500; Stacey *et al.* (1996) *J. Immunol.* 157: 2116-2122), CpG-induced expression of IL-6 by wild-type and MyD88 was examined in deficient macrophages. Cells derived from caspase-1 knock-out mice were used as a control for IL-1-mediated induction of IL-6. The production of IL-6 in response to CpG stimulation was completely abolished in MyD88 -/- macrophages, but was normal in caspase-1, TLR2- and TLR4-deficient cells (Figure 10A). Oligonucleotides consisting of inverted CpG sequence (GpC) were used as a control, and as expected did not induce detectable amounts of IL-6 (Figure10A).

Example 15. CpG-DNA-Induced IκBα Degradation

We next tested whether activation of the NF-κB signaling pathway is deficient in MyD88 -/- macrophages. Peritoneal macrophages were stimulated with CpG-DNA, or LPS as a control, for 0, 10, 20, 60, and 90 minutes and lysed thereafter. For each timepoint, 30 mg total protein was processed for SDS-PAGE and analyzed by immunoblotting for IκBα protein. (Figure 10B). In wild-type cells, both LPS and CpG-DNA induced NF-κB activation, as evidenced by the degradation of IκB protein (Figure 10B). In MyD88 -/- macrophages, LPS still induced IκB degradation, albeit with delayed kinetics, as is consistent with published observations (Kawai *et al.* (1999) *Immunity* 11: 115-122). However, unlike LPS, CpG-DNA did not induce IκB degradation in MyD88 -/- macrophages (Figure 10B). Therefore, while both LPS and CpG-DNA signal through MyD88, the signaling pathways initiated by these stimuli are not identical, reflecting a possibility that different TLRs can activate overlapping but distinct signaling pathways.

Example 16. CpG and IL-2 Production in Dendritic Cells

CpG-DNA has been shown to be a potent inducer of DC activation (Sparwasser *et al.* (1998) *Eur. J. Immunol.* 28: 2045-2054). DC play a pivotal role in the initiation of the adaptive immune responses (Banchereau *et al.* (1998) *Nature* 392: 245-252). Upon interaction with microbe-derived products (PAMPs) in peripheral tissues, DC undergo developmental changes collectively referred to as maturation (Banchereau *et al.* (1998) *Nature* 392: 245-252). The hallmark of DC maturation is the induction of cell surface expression of CD80 and CD86 molecules, as well as migration into lymphoid tissues and production of cytokines such as IL-12 (Banchereau *et al.* (1998) *Nature* 392: 245-252). We tested therefore, whether the induction of DC maturation by CpG-DNA is mediated by the MyD88 signaling pathway. MyD88 -/- animals produce IL-12 when stimulated with CpG oligonucleotides. Wild-type, B10/ScCr, and MyD88 -/- bone marrow DC, were prepared from bone marrow suspensions cultured for 5 days in DC Growth Medium (RPMI 5% FC + 1% GM-CSF) and stimulated with 10 mm CpG or 10 mm GpC oligonucleotides or left untreated. Supernatants were taken 24 h and 48 h after stimulation and analyzed for IL-12 by ELISA using specific capture and detection antibodies.

The results, shown in Figure 11, are from one of three independently performed experiments. Consistent with published reports, CpG-DNA induced secretion of large amounts of IL-12 by DC from the wild-type mice. However, no detectable IL-12 was produced in response to CpG stimulation by DC derived from MyD88 knock-out mice (Figure 11). As expected, DC from TLR4-deficient mice produced wild-type levels of IL-12 in response to CpG-DNA (Figure 11).

Example 17. CpG/ Eα Chimeric Construct

A non-protein PAMP, CpG, was conjugated to the characterized mouse antigen, Eα, through a PEG polymer linker and/or copolymers of D-lysine and D-glutamate, according to the methods described in U.S. Pat. No. 6,06,0056. A CpG-DNA derivative, comprising CpG_{40} was used as the non-protein PAMP.

All articles, patents and other materials referred to below are specifically incorporated herein by reference.

While this invention has been disclosed with reference to specific embodiments, it is apparent that other embodiments and variations of this invention may be devised by others skilled in the art without departing from the true spirit and scope of the invention. The appended claims are intended to be construed to include all such embodiments and equivalent variations.

I CLAIM:

1. A fusion protein comprising an isolated PAMP or an immunostimulatory portion or immunostimulatory derivative thereof and an antigen or an immunogenic portion or immunogenic derivative thereof.

2. The fusion protein of claim 1, wherein the PAMP is selected from the group consisting of peptides, proteins, lipoproteins and glycoproteins.

3. The fusion protein of claim 1, wherein the PAMP is a ligand for a PRR.

4. The fusion protein of claim 1, wherein the antigen is obtainable from sources selected from the group consisting of bacteria, viruses, fungi, yeast, protozoa, metazoa, tumors, malignant cells, abnormal neural cells, arthritic lesions, cardiovascular lesions, plants, animals, humans, allergens, and hormones.

5. The fusion protein of claim 1, wherein the antigen is microbe-related, allergen-related or related to abnormal human or animal cells.

6. The fusion protein of claim 1, wherein the PAMP and antigen are linked by a chemical linker.

7. The fusion protein of claim 1, wherein the fusion protein further comprises one or more additional PAMPs or immunostimulatory portions or immunostimulatory derivatives thereof, and wherein the PAMPs, immunostimulatory portions or immunostimulatory derivatives of the fusion protein are either identical or different.

8. The fusion protein of claim 1, wherein the vaccine further comprises one or more additional antigens or immunogenic portions or immunogenic derivatives thereof, and wherein the antigens, immunogenic portions or immunogenic derivatives of the fusion protein are either identical or different.

9. The fusion protein of claim 1, wherein the fusion protein further comprises one or more additional PAMPs or immunostimulatory portions or immunostimulatory derivatives thereof, and one or more additional antigens or immunogenic portions or immunogenic derivatives thereof, and wherein the

PAMPs, immunostimulatory portions or immunostimulatory derivatives thereof, and/or the antigens , immunogenic portions or immunogenic derivatives of the fusion protein are either identical or different.

10. The fusion protein of claim 1, wherein the fusion protein further comprises one or more carrier proteins.

11. The fusion protein of claim 1, wherein the PAMP and the antigen are separated by a spacer.

12. The fusion protein of claim 1, wherein the PAMP is BLP.

13. The fusion protein of claim 12, wherein BLP is the amino acid sequence of SEQ ID NO: 2.

14. The fusion protein of claim 1, wherein the antigen is selected from the group consisting of amyloid-β peptide, listeriolysin, HIV gp120 and p24, Ra5G and TRP-2, EGFR, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

15. The fusion protein of claim 1, wherein the PAMP is a peptide mimetic of a non-protein PAMP and/or the antigen is a peptide mimetic of a non-protein antigen.

16. A fusion protein comprising a leader sequence, a consensus sequence, and an antigen sequence, wherein the consensus sequence is either a glycosylation or lipidation consensus sequence.

17. The fusion protein of claim 16, wherein the consensus sequence is either a glycosylation or a lipidation consensus sequence.

18. The fusion protein of claim 16, wherein the leader sequence signals post-translational glycosylation or lipidation of the consensus sequence.

19. The fusion protein of claim 18, wherein the leader peptide is selected from the group consisting of:

a) the amino acid sequence of SEQ ID NO: 3;

b) the amino acid sequence of SEQ ID NO: 4;

c) the amino acid sequence of SEQ ID NO: 5;

d) the amino acid sequence of SEQ ID NO: 6; and

e) the amino acid sequence of SEQ ID NO: 7.

20. The fusion protein of claim 16, wherein the consensus sequence is CXXN (SEQ ID NO: 1).

21. The fusion protein of claim 17, wherein the consensus sequence is CXXN (SEQ ID NO: 1).

22. The fusion protein of claim 16, wherein the antigen is obtainable from sources selected from the group consisting of bacteria, viruses, fungi, yeast, protozoa, metazoa, tumors, malignant cells, abnormal neural cells, arthritic lesions, cardiovascular lesions, plants, animals, humans, allergens, and hormones.

23. The fusion protein of claim 16, wherein the antigen is microbe-related, allergen-related or related to abnormal human or animal cells.

24. A recombinant vector comprising nucleotides encoding the fusion protein of claim 1 or claim 16.

25. A host cell comprising the recombinant vector of claim 24.

26. The host cell of claim 25, wherein the host cell is that of a host selected from the group consisting of bacteria, yeast, plants, animals and insects.

27. The host cell of claim 25, wherein the host cell is a bacteria which produces the PAMP naturally.

28. The host cell of claim 25, wherein the host cell is a bacteria that lipidates the PAMP.

29. A method of producing a fusion protein comprising a PAMP or an immunostimulatory portion or immunostimulatory derivative thereof and an antigen or an immunogenic portion or immunogenic derivative thereof, said method comprising culturing the cell of claim 16 and isolating the fusion protein produced by the cell.

30. A vaccine comprising the fusion protein of claim 1 or claim 16 and a pharmaceutically acceptable carrier.

31. The vaccine of claim 30, wherein the antigen is associated with disease.

32. The vaccine of claim 30, wherein the antigen is allergen-related or related to abnormal human or animal cells.

33. The vaccine of claim 30, wherein the antigen is a hormone.

34. The vaccine of claim 30, wherein the antigen is an amyloid-β peptide.

35. The vaccine of claim 30, wherein the PAMP is a peptide mimetic of a non-protein PAMP.

36. The vaccine of claim 30, wherein the antigen is a peptide mimetic of a non-protein antigen.

37. A method of immunizing an animal comprising the step of administering to the animal the vaccine of claim 30.

38. A method of immunizing a mammal comprising the step of administering to the mammal the vaccine of claim 30.

39. The method of claim 38, wherein the mammal is a human.

40. The method of claim 37, wherein the vaccine is administered parenterally, intravenously, orally, using suppositories, or via the mucosal surfaces.

41. The method of claim 39, wherein the antigen is amyloid-β peptide or an immunogenic portion thereof.

42. The method of claim 39,wherein the fusion protein is administered to a human diagnosed with Alzheimer's disease.

43. A method of treating a subject comprising the steps of administering antibodies or activated immune cells to a subject and administering a vaccine comprising the fusion protein of claim 1 or claim 16, wherein the antibodies or activated immune cells are directed against the antigen of the fusion protein.

44. The method of claim 43, wherein the antibodies are monoclonal.

45. A method of treating a subject comprising the steps of administering a vaccine comprising the fusion protein of claim 1 or claim 16 and an agent selected from the group consisting of: chemotherapeutic agents and anti-angiogenic agents.

46. The method of claim 45, wherein the chemotherapeutic agent is an anti-cancer agent.

47. A method of treating a subject comprising the steps of administering a vaccine comprising the fusion protein of claim 1 or claim 16 in combination with surgery or radiation therapy.

48. A fusion protein comprising an isolated PAMP and an antigen, wherein the antigen is a self-antigen.

49. The fusion protein of claim 48, wherein the antigen is selected from the group consisting of amyloid-β peptide, TRP-2, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2,

HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

50. The fusion protein of claim 48, wherein the PAMP is selected from the group consisting of peptides, proteins, lipoproteins, and glycoproteins.

51. The fusion protein of claim 48, wherein the PAMP is a ligand for a PRR.

52. The fusion protein of claim 48, wherein the PAMP is lipidated.

53. The fusion protein of claim 48, wherein the antigen is obtainable from sources selected from the group consisting of tumors, malignant cells, abnormal neural cells, arthritic lesions, and cardiovascular lesions.

54. The fusion protein of claim 48, wherein the antigen is related to abnormal human or animal cells.

55. The fusion protein of claim 48, wherein the PAMP and antigen are linked by a chemical linker.

56. The fusion protein of claim 48, wherein the fusion protein further comprises one or more additional PAMPs, and wherein the PAMPs are either identical or different.

57. The fusion protein of claim 48, wherein the fusion protein further comprises one or more additional antigens, and wherein the antigens are either identical or different.

58. The fusion protein of claim 48, wherein the fusion protein further comprises one or more additional PAMPs and one or more additional antigens and wherein the PAMPs, and/or the antigens, are either identical or different.

59. The fusion protein of claim 48, wherein the fusion protein further comprises one or more carrier proteins.

60. The fusion protein of claim 48, wherein the PAMP and the antigen are separated by a spacer.

61. The fusion protein of claim 48, wherein the PAMP is a BLP, an OMP, an OSP, a Flagellin or a porin.

62. The fusion protein of claim 61, wherein the PAMP is the BLP which has the amino acid sequence of SEQ ID NO: 2.

63. The fusion protein of claim 48, wherein the PAMP is a peptide mimetic of a non-protein PAMP and/or the antigen is a peptide mimetic of a non-protein antigen.

64. A method of stimulating an innate immune response in an animal and thereby enhancing the adaptive immune response to a foreign or self-antigen which comprises co-administering a PAMP with the foreign or self antigen.

65. The method of claim 64 wherein the innate immune response is stimulated by activating one or more of the Toll-like Receptors.

66. The method of claim 65 wherein the animal is a mammal.

67. The method of claim 66 wherein the adaptive immune response is enhanced by the activation of APCs by the activation of the one or more Toll-like Receptors.

68. The method of claim 67 wherein the antigen is of bacterial, viral, protozoan, metazoan, or fungal origin.

69. The method of claim 68 wherein the PAMP and antigen are co-administered in the form of a fusion protein.

70. The method of claim 69 wherein the PAMP is selected from the group consisting of: bacterial lipoprotein, bacterial outer membrane protein, bacterial outer surface protein, Flagellins, or porins.

71. The method of claim 70 wherein the PAMP is selected from the group consisting of: Borrelia ospA, Borrelia ospB, Borrelia ospC, the lipidated tetrapeptide of bacterial lipoprotein and Klebsiella ompA.

72. The method of claim 71 wherein the PAMP is the lipidated tetrapeptide of bacterial lipoprotein.

73. The method of claim 70 wherein the self-antigen is selected from the group consisting of amyloid-β peptide, TRP-2, EGFR, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

74. The method of claim 67 wherein the antigen is a self-antigen.

75. The method of claim 73 wherein the PAMP and antigen or co-administered in the form of a fusion protein.

76. The method of claim 74 wherein the PAMP is selected from the group consisting of: bacterial lipoprotein, bacterial outer membrane protein, bacterial outer surface protein, Flagellins, or porins.

77. The method of claim 75 wherein the PAMP is selected from the group consisting of: Borrelia ospA, Borrelia ospB, Borrelia ospC, the lipidated tetrapeptide of bacterial lipoprotein and Klebsiella ompA.

78. The method of claim 77 wherein the PAMP is the lipidated tetrapeptide of bacterial lipoprotein.

79. The method of claim 75 wherein the self-antigen is selected from the group consisting of amyloid-β peptide, TRP-2, EGFR, prostate-specific antigen (PSA), prostate-specific membrane antigen (PSMA), Her-2neu, SPAS-1, TRP-1, tyrosinase, Melan A/Mart-1, gp100, BAGE, GAGE, GM2 ganglioside, kinesin 2, TATA element modulatory factor 1, tumor protein D52, MAGE D, ING2, HIP-55, TGF-1 anti-apoptotic factor, MAGE-1, HOM-Mel-40/SSX2, NY-ESO-1EGFR, CEA, MAGE D, Her-2neu, NY-ESO-1, glycoprotein MUC1 and MUC10 mucins, p53, EGFR, CDC27, triosephosphate isomerase, HLA-DRB1, HLA-DR1, HLA-DR6 B1, CD11a, LFA-1, IFNγ, IL-10, TCR analogs, IgR analogs, 21-hydoxylase, calcium sensing receptor, tyrosinase, LDL receptor, glutamic acid decarboxylase (GAD), insulin B chain, PC-1, IA-2, IA-2b, GLIMA-38 and NMDA.

80. The method of claim 69 wherein the fusion protein is formulated with a pharmaceutically acceptable adjuvant.

81. The fusion protein of claim 48, wherein the antigen is selected from the group of antigens consisting of vascular endothelial growth factors, vascular endothelial growth factor receptors, fibroblast growth factors and fibroblast growth factor receptors.

82. A vaccine which comprises a PAMP conjugated with a foreign or self antigen that stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

83. A vaccine which comprises a PAMP conjugated with a foreign or self antigen which, when administered at a therapeutically active dose, stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

84. A method of treatment comprising the steps of administering to an individual a vaccine which comprises a PAMP conjugated with a foreign or self antigen

which stimulates an innate immune response in an animal and thereby enhances the adaptive immune response to a foreign or self-antigen but does not lead to undesirable levels of inflammation.

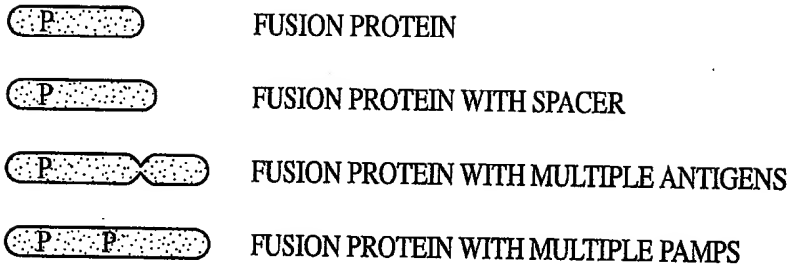

P
FUSION PROTEIN
P
FUSION PROTEIN WITH SPACER
P
FUSION PROTEIN WITH MULTIPLE ANTIGENS
P P
FUSION PROTEIN WITH MULTIPLE PAMPS

FIG. 1

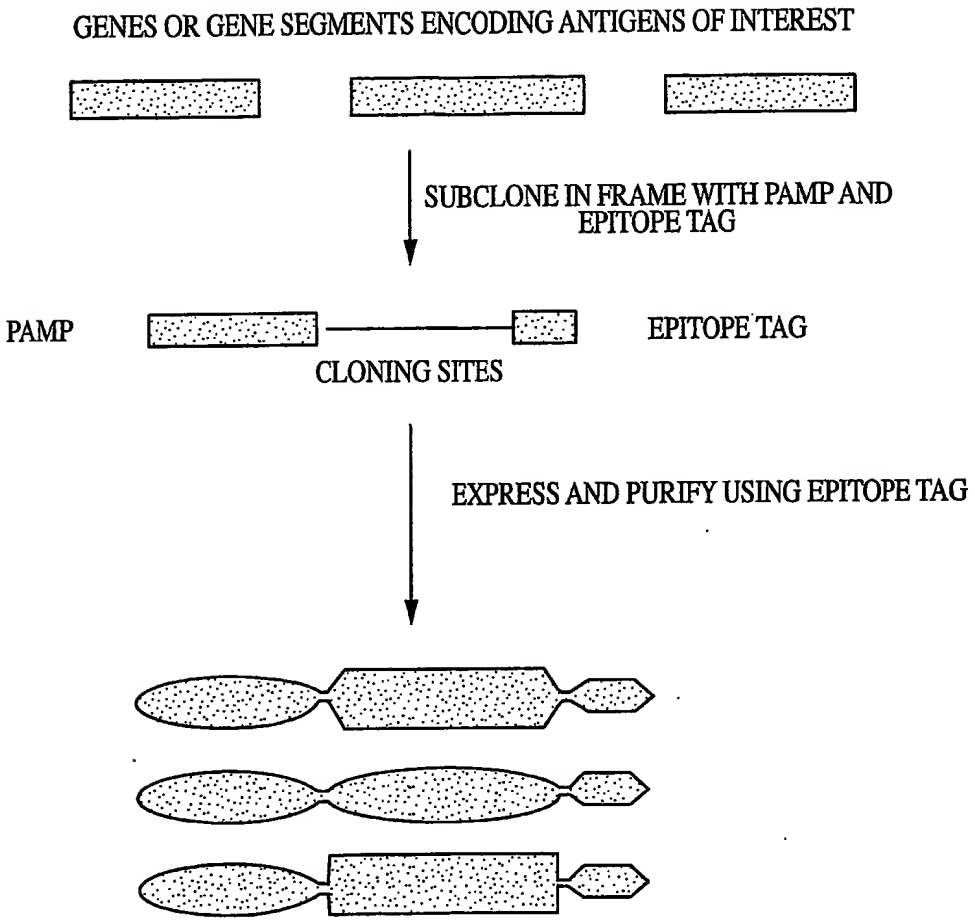

GENES OR GENE SEGMENTS ENCODING ANTIGENS OF INTEREST
SUBCLONE IN FRAME WITH PAMP AND EPITOPE TAG
PAMP
EPITOPE TAG
CLONING SITES
EXPRESS AND PURIFY USING EPITOPE TAG

FIG. 2

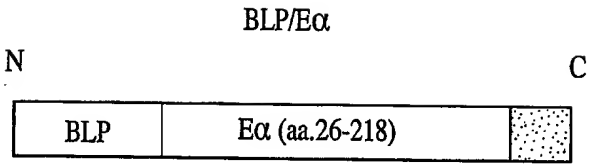


FIG. 3

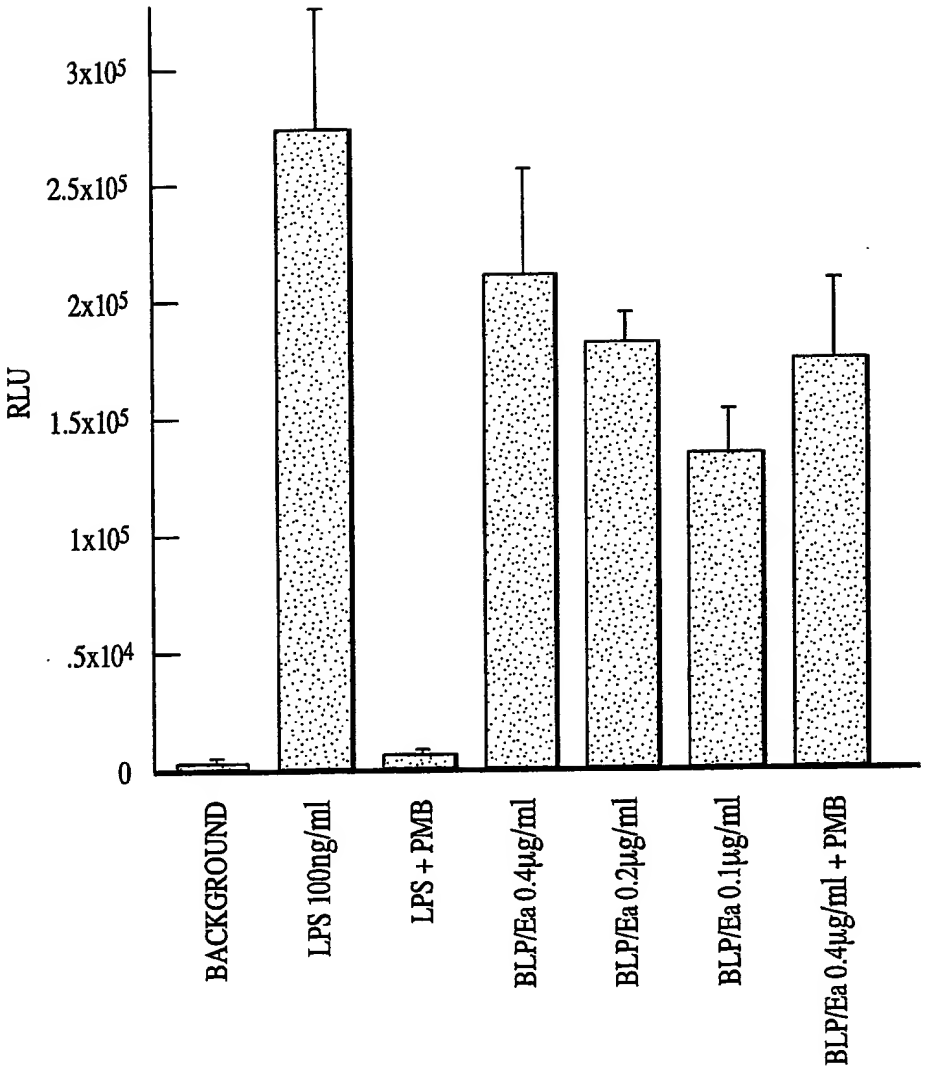

RLU
3x10^5
2.5x10^5
2x10^5
1.5x10^5
1x10^5
.5x10^4
0
BACKGROUND
LPS 100ng/ml
LPS + PMB
BLP/Ea 0.4µg/ml
BLP/Ea 0.2µg/ml
BLP/Ea 0.1µg/ml
BLP/Ea 0.4µg/ml + PMB

FIG. 4

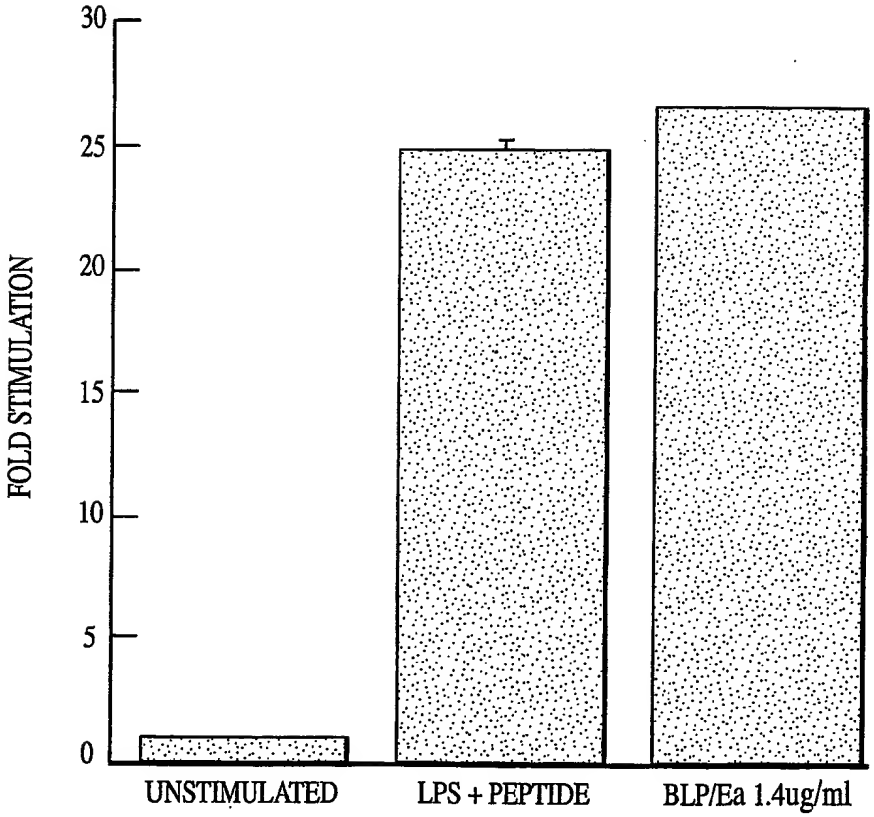
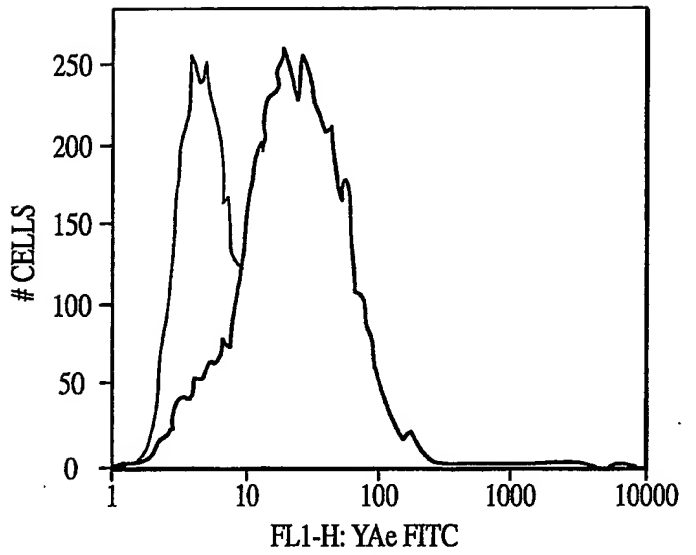

30
25
20
15
10
5
0
FOLD STIMULATION
UNSTIMULATED
LPS + PEPTIDE
BLP/Ea 1.4ug/ml

FIG. 5


250
200
150
100
50
0
CELLS
1
10
100
1000
10000
FL1-H: YAe FITC

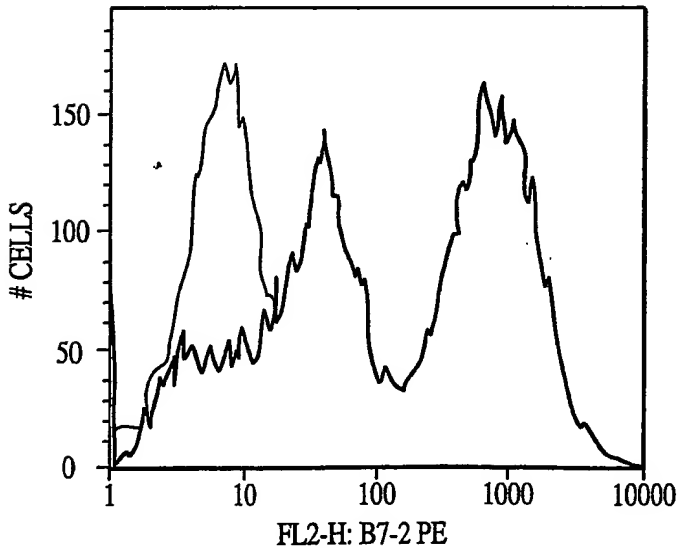

150
100
50
0
CELLS
1
10
100
1000
10000
FL2-H: B7-2 PE

FIG. 6

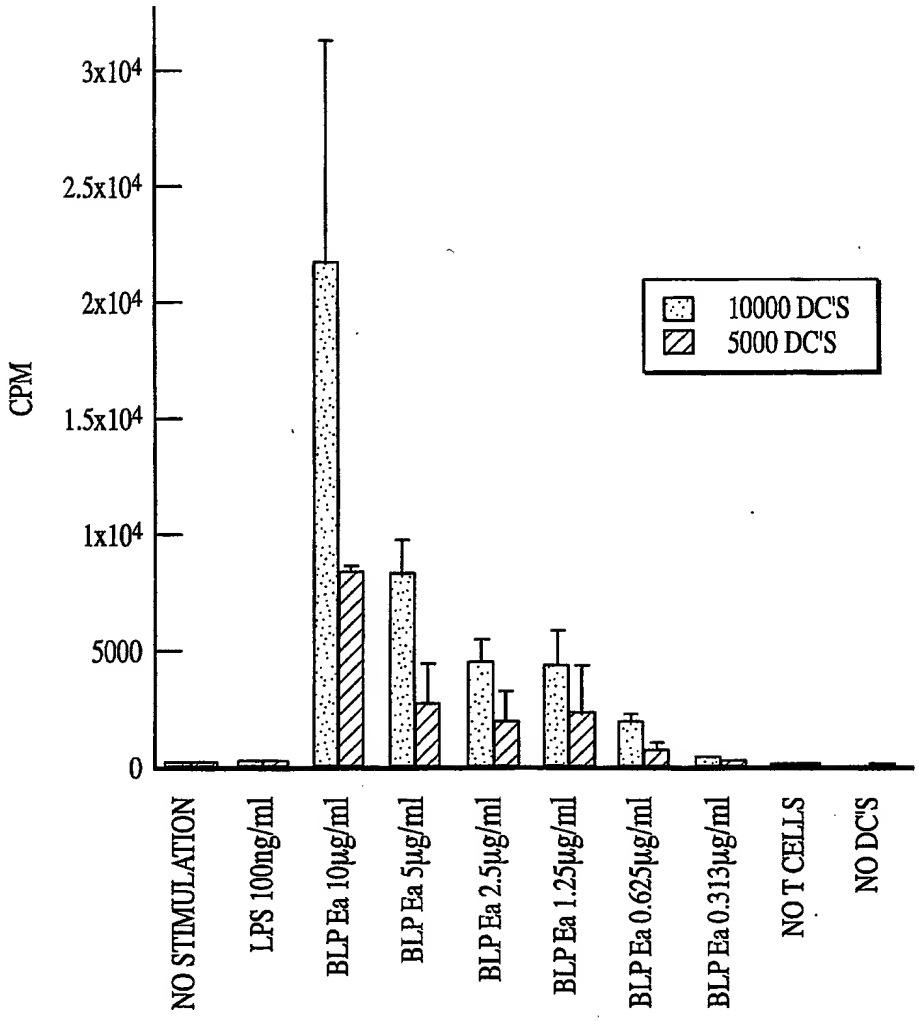

CPM
3x10⁴
2.5x10⁴
2x10⁴
1.5x10⁴
1x10⁴
5000
0
10000 DC'S
5000 DC'S
NO STIMULATION
LPS 100ng/ml
BLP Ea 10µg/ml
BLP Ea 5µg/ml
BLP Ea 2.5µg/ml
BLP Ea 1.25µg/ml
BLP Ea 0.625µg/ml
BLP Ea 0.313µg/ml
NO T CELLS
NO DC'S

FIG. 7

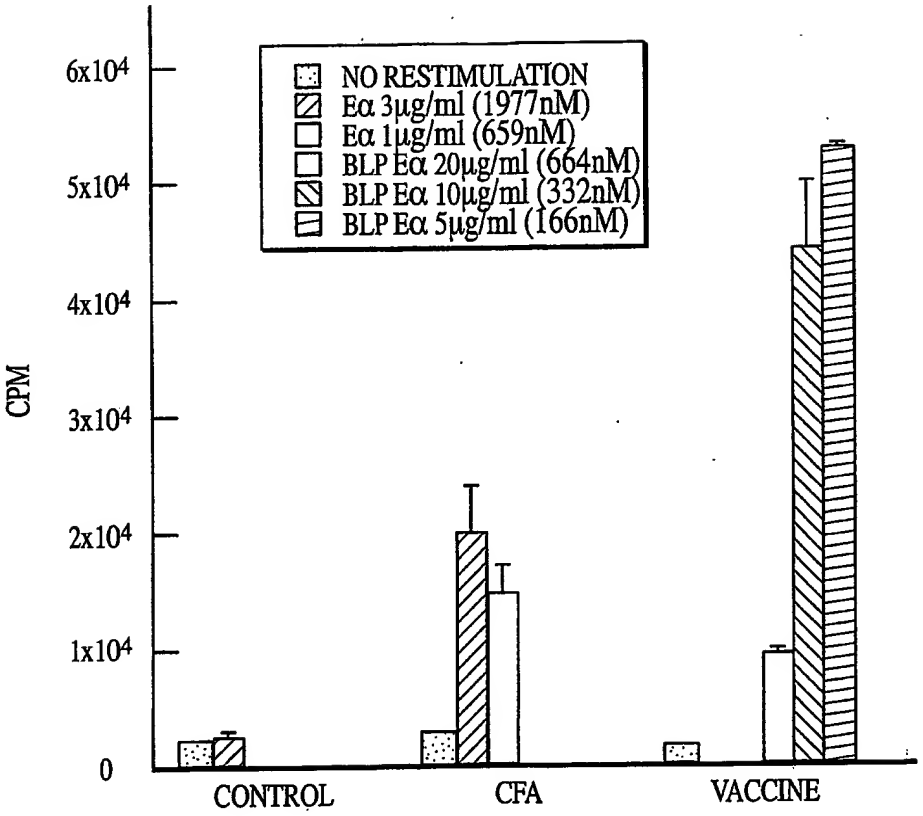

NO RESTIMULATION
Eα 3μg/ml (1977nM)
Eα 1μg/ml (659nM)
BLP Eα 20μg/ml (664nM)
BLP Eα 10μg/ml (332nM)
BLP Eα 5μg/ml (166nM)
CPM
6x10⁴
5x10⁴
4x10⁴
3x10⁴
2x10⁴
1x10⁴
0
CONTROL
CFA
VACCINE

FIG. 8

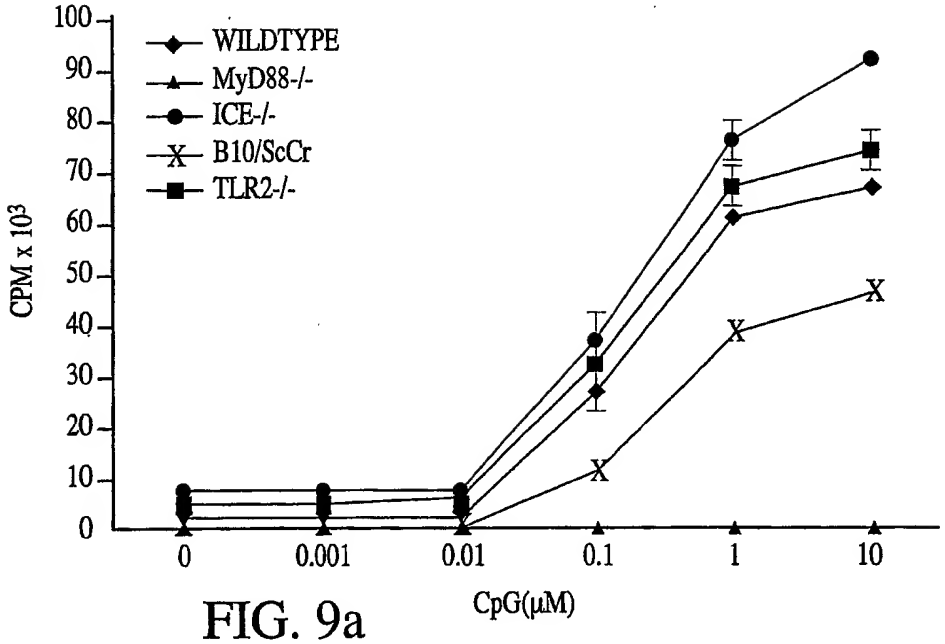

WILDTYPE
MyD88-/-
ICE-/-
B10/ScCr
TLR2-/-
CPM x 10³
100
90
80
70
60
50
40
30
20
10
0
0
0.001
0.01
0.1
1
10
CpG(μM)

FIG. 9a

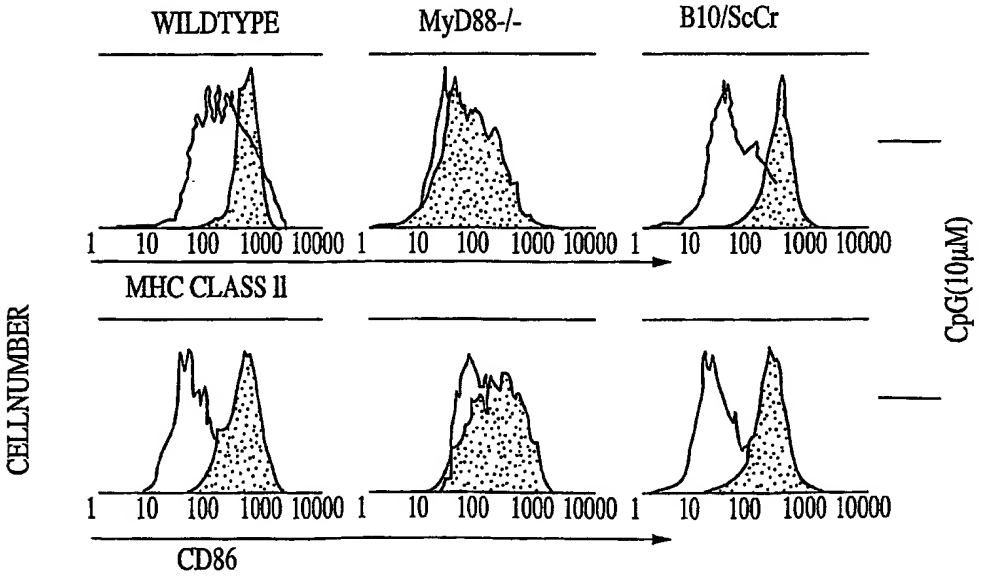

WILDTYPE
MyD88-/-
B10/ScCr
1 10 100 1000 10000
MHC CLASS II
CELLNUMBER
CD86
CpG(10μM)

FIG. 9b

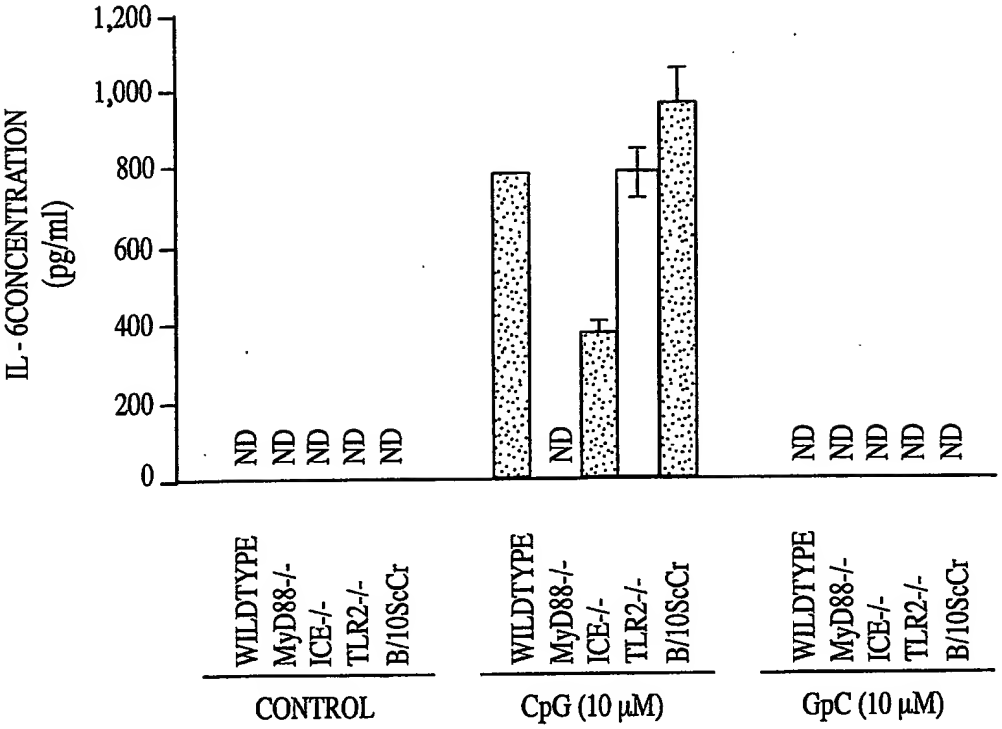


FIG. 10a

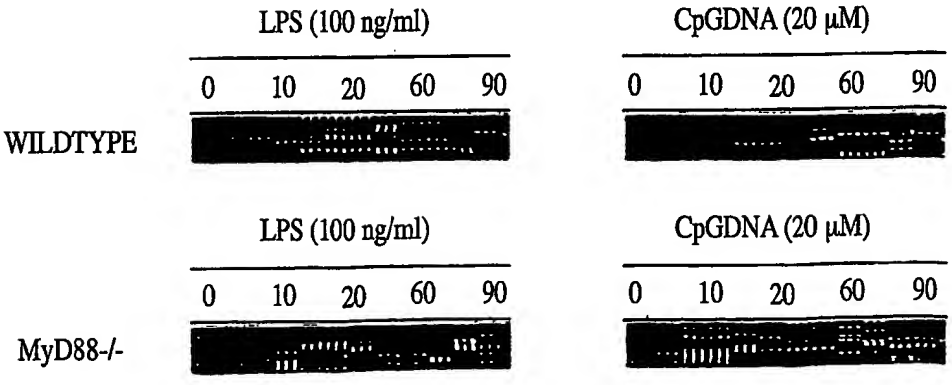


FIG. 10b

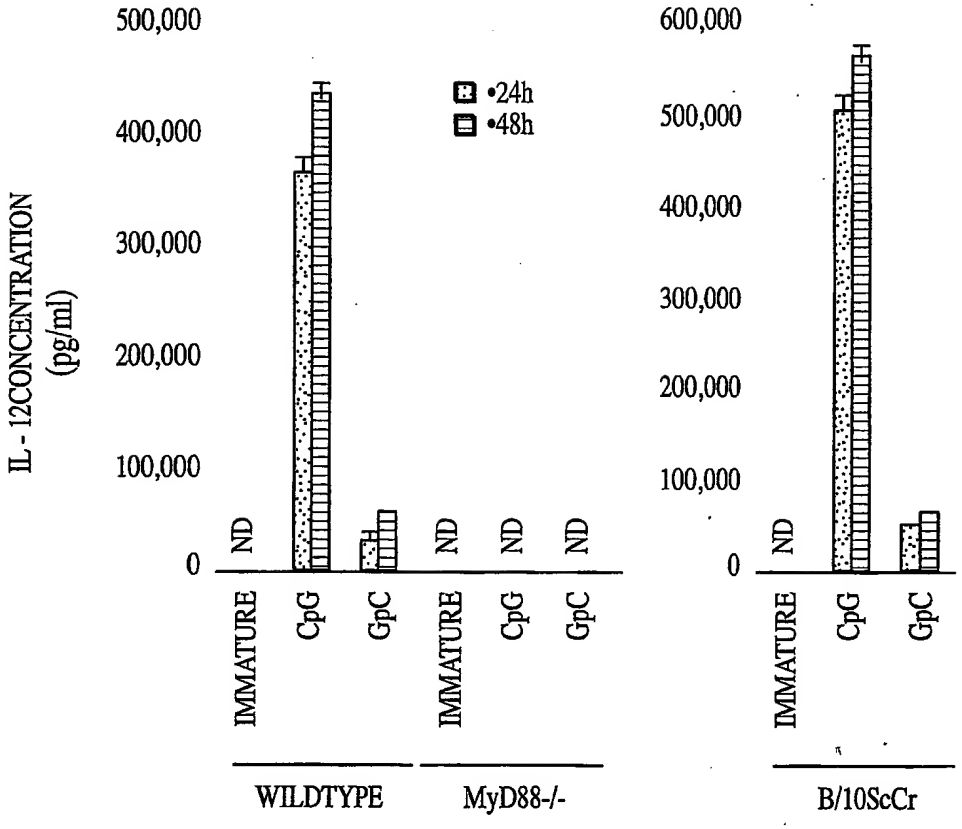

IL - 12CONCENTRATION (pg/ml)
500,000
400,000
300,000
200,000
100,000
0
•24h
•48h
ND
IMMATURE
CpG
GpC
WILDTYPE
MyD88-/-
600,000
B/10ScCr

FIG. 11

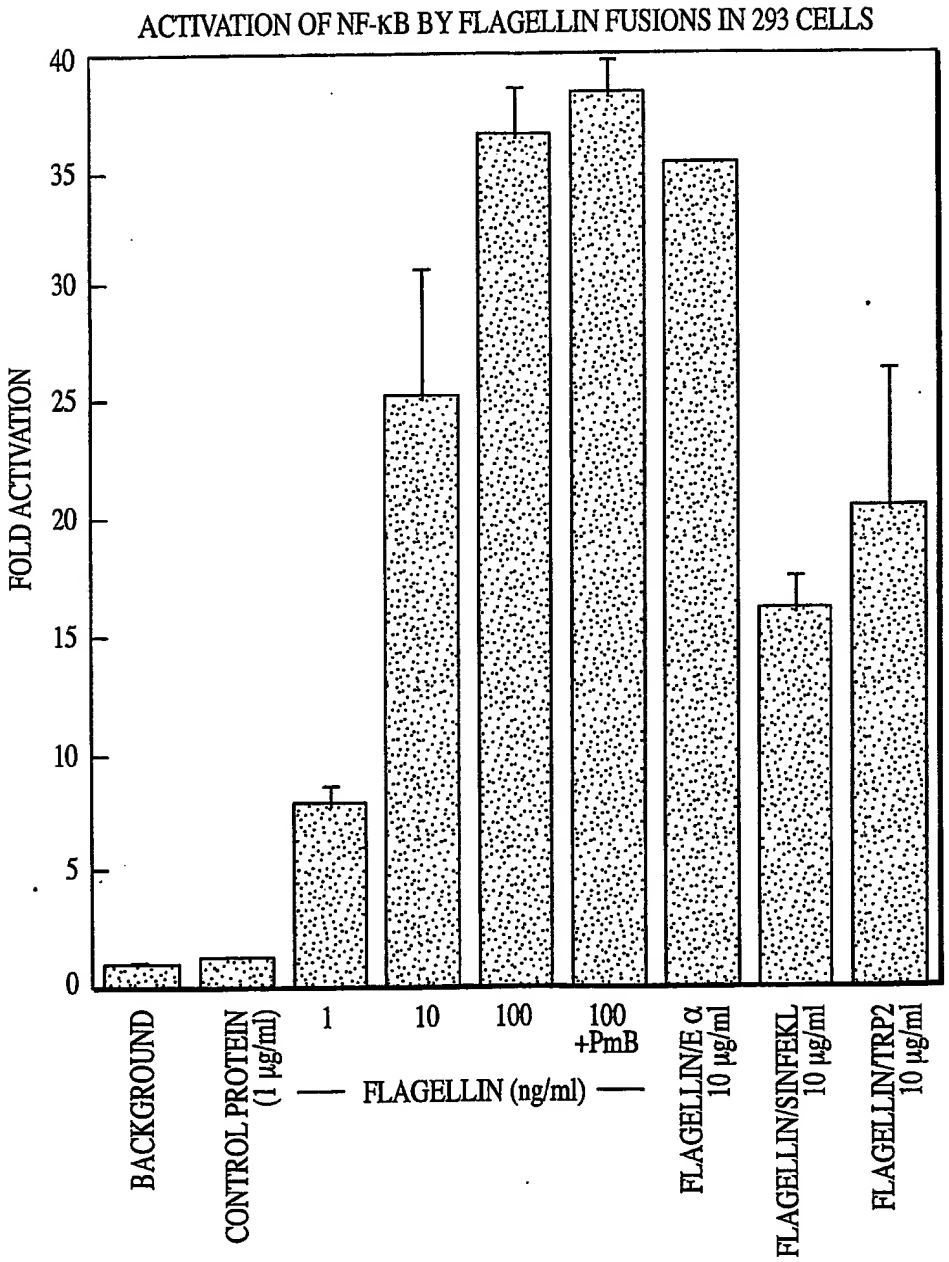

ACTIVATION OF NF-κB BY FLAGELLIN FUSIONS IN 293 CELLS
FOLD ACTIVATION
40
35
30
25
20
15
10
5
0
BACKGROUND
CONTROL PROTEIN (1 μg/ml)
1
10
100
100 +PmB
FLAGELLIN (ng/ml)
FLAGELLIN/E α 10 μg/ml
FLAGELLIN/SINFEKL 10 μg/ml
FLAGELLIN/TRP2 10 μg/ml

FIG. 12

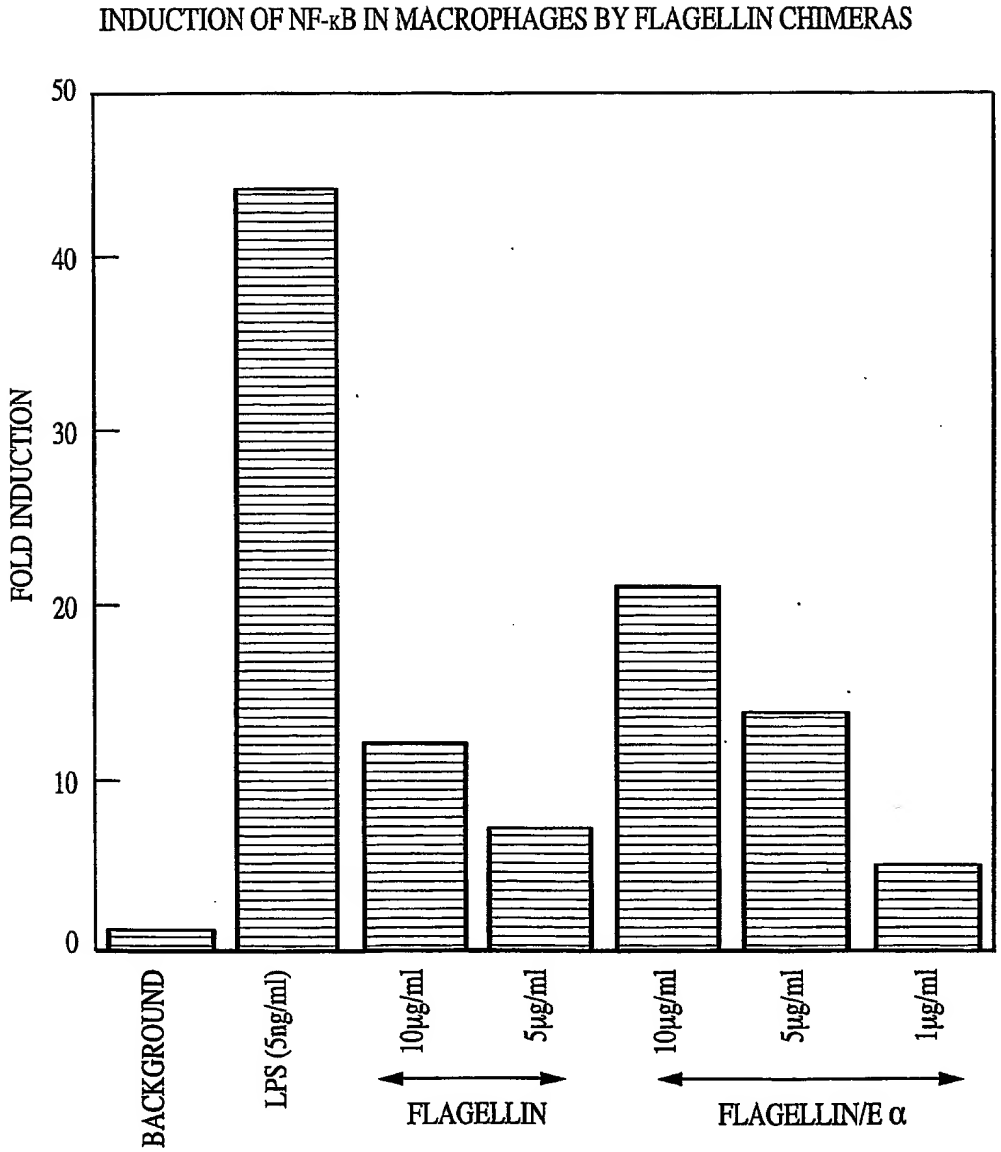

INDUCTION OF NF-κB IN MACROPHAGES BY FLAGELLIN CHIMERAS
FOLD INDUCTION
50
40
30
20
10
0
BACKGROUND
LPS (5ng/ml)
10μg/ml
5μg/ml
FLAGELLIN
10μg/ml
5μg/ml
1μg/ml
FLAGELLIN/E α

FIG. 13

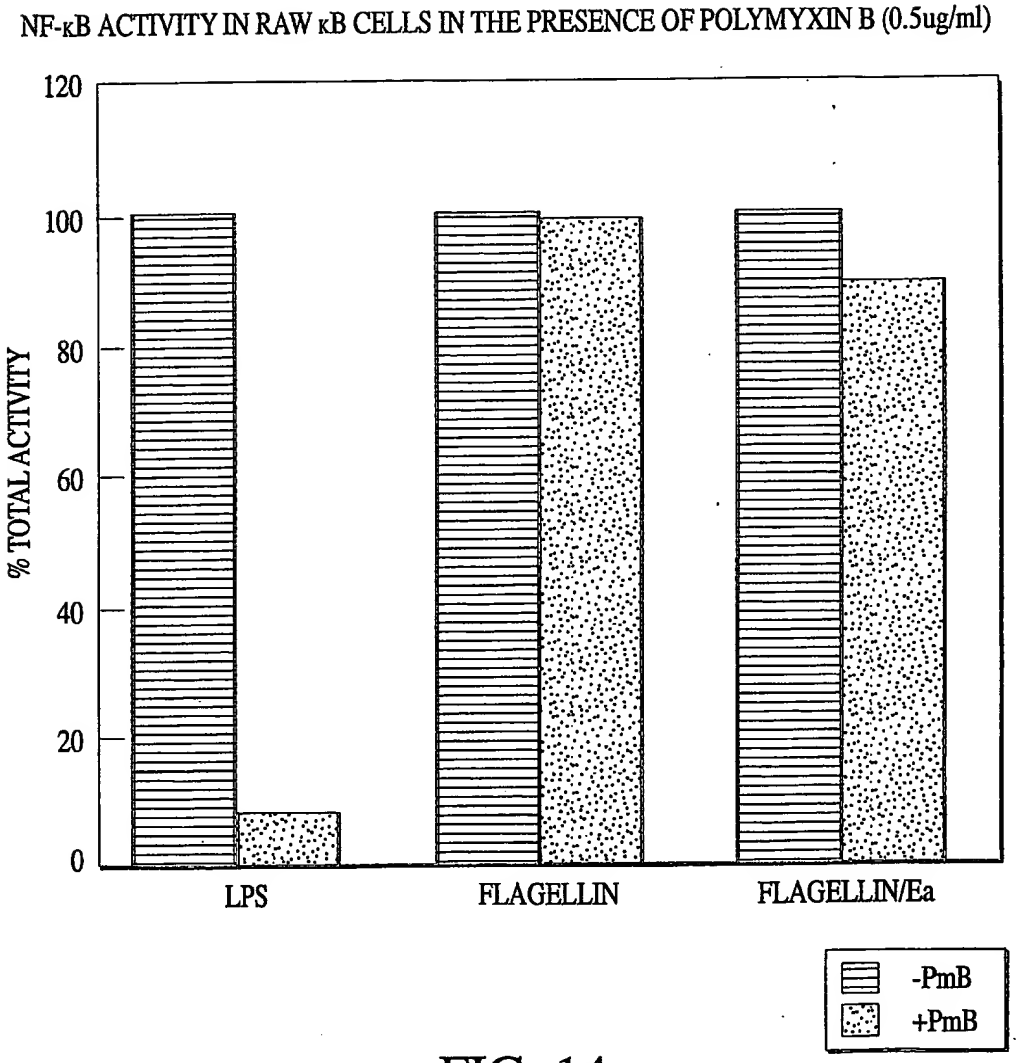

NF-κB ACTIVITY IN RAW κB CELLS IN THE PRESENCE OF POLYMYXIN B (0.5ug/ml)
% TOTAL ACTIVITY
120
100
80
60
40
20
0
LPS
FLAGELLIN
FLAGELLIN/Ea
-PmB
+PmB

FIG. 14

FIG. 15

```
MET LYS ALA THR LYS LEU VAL LEU GLY ALA
1               5                  10

VAL ILE LEU GLY SER THR LEU LEU ALA GLY
                15                  20
```

FIG. 16

```
MET ASN ARG THR LYS LEU VAL LEU GLY ALA
1               5                  10

VAL ILE LEU GLY SER THR LEU LEU ALA GLY
                15                 20
```

FIG. 17

```
MET ASN ARG THR LYS LEU VAL LEU GLY ALA
1               5                   10

VAL ILE LEU GLY SER HIS SER ALA GLY
                15
```

FIG. 18

```
MET LYS ALA LYS ILE VAL LEU GLY ALA VAL
1               5                  10

ILE LEU ALA SER GLY LEU LEU ALA GLY
                15
```

FIG. 19

```
MET LYS LYS TYR LEU LEU GLY ILE GLY LEU
1               5                   10
ILE LEU ALA LEU ILE ALA
                15
```

FIG. 20A

GCAGCATAAT AAGCAGTATG GCTGGAGCAC TCTGTAAATT 40
AACTCAATTA GACAGAGCCT GATTTAACAA GGAAGACTGG 80
CGAGAAGCTC CCCTCATTAA ACCTGATGTT AGAGGAGCTT 120
CGGATGAAAT TAAATCAGTG TTAGTTGTTT GAGTCACATA 160
AAATTGCATG AGCGTGTACA CATGTGCACA CGTGTAGGCT 200
CTGTGATTTA GGTGGGAATT TTGAGAGGAG AGGAAAGGGC 240
TAGAACTAAA CCCAAAGAAA AGGAAAGAAG AGAAGAGGAA 280
AGGAAAGAAA AAAGAAAAGG CAATTTGAGT GAGTAAAGGT 320
TCCAGAACTC AGGAGTGGAA GACAAGGAGT AAAGTCAGAC 360
AGAAACCAGG TGGGACGCCG GCCAGGCCTC CCAATTAAGA 400
AGGCATGGGC CTTGTGGGAT GGGGGCTTCT GCTGGGTTGT 440
CTGGGCTGCG GAATTCTGCT CAGAGCTCGG GCTCAGTTTC 480
CCCGAGTCTG CATGACCTTG GATGGCGTGC TGAACAAGGA 520
ATGCTGCCCG CCTCTGGGTC CCGAGGCAAC CAACATCTGT 560
GGATTTCTAG AGGGCAGGGG GCAGTGCGCA GAGGTGCAAA 600
CAGACACCAG ACCCTGGAGT GGCCCTTATA TCCTTCGAAA 640
CCAGGATGAC CGTGAGCAAT GGCCGAGAAA ATTCTTCAAC 680
CGGACATGCA AATGCACAGG AAACTTTGCT GGTTATAATT 720
GTGGAGGCTG CAAGTTCGGC TGGACCGGCC CCGACTGTAA 760
TCGGAAGAAG CCGGCCATCC TAAGACGGAA TATCCATTCC 800
CTGACTGCCC AGGAGAGGGA GCAGTTCTTG GGCGCCTTAG 840
ACCTGGCCAA GAAGAGTATC CATCCAGACT ACGTGATCAC 880
CACGCAACAC TGGCTGGGGC TGCTCGGACC CAACGGGACC 920
CAGCCCCAGA TCGCCAACTG CAGCGTGTAT GACTTTTTTG 960
TGTGGCTCCA TTATTATTCT GTTCGAGACA CATTATTAGG 1000
TCCAGGACGC CCCTATAAGG CCATTGATTT CTCTCACCAA 1040
GGGCCTGCCT TTGTCACGTG GCACAGGTAC CATCTGTTGT 1080
GGCTGGAAAG AGAACTCCAG AGACTCACTG GCAATGAGTC 1120
CTTTGCGTTG CCCTACTGGA ACTTTGCAAC CGGGAAGAAC 1160
GAGTGTGACG TGTGCACAGA CGACTGGCTT GGAGCAGCAA 1200
GACAAGATGA CCCAACGCTG ATTAGTCGGA ACTCGAGATT 1240
CTCTACCTGG GAGATTGTGT GCGACAGCTT GGATGACTAC 1280
AACCGCCGGG TCACACTGTG TAATGGAACC TATGAAGGTT 1320
TGCTGAGAAG AAACAAAGTA GGCAGAAATA ATGAGAAACT 1360
GCCAACCTTA AAAAATGTGC AAGATTGCCT GTCTCTCCAG 1400
AAGTTTGACA GCCCTCCCTT CTTCCAGAAC TCTACCTTCA 1440
GCTTCAGGAA TGCACTGGAA GGGTTTGATA AAGCAGACGG 1480
AACACTGGAC TCTCAAGTCA TGAACCTTCA TAACTTGGCT 1520
CACTCCTTCC TGAATGGGAC CAATGCCTTG CCACACTCAG 1560

FIG. 20B

```
CAGCCAACGA CCCTGTGTTT GTGGTCCTCC ACTCTTTTAC 1600
AGACGCCATC TTTGATGAGT GGCTGAAGAG AAACAACCCT 1640
TCCACAGATG CCTGGCCTCA GGAACTGGCA CCCATTGGTC 1680
ACAACCGAAT GTATAACATG GTCCCCTTCT TCCCACCGGT 1720
GACTAATGAG GAGCTCTTCC TAACCGCAGA GCAACTTGGC 1760
TACAATTACG CCGTTGATCT GTCAGAGGAA GAAGCTCCAG 1800
TTTGGTCCAC AACTCTCTCA GTGGTCATTG GAATCCTGGG 1840
AGCTTTCGTC TTGCTCTTGG GGTTGCTGGC TTTTCTTCAA 1880
TACAGAAGGC TTCGCAAAGG CTATGCGCCC TTAATGGAGA 1920
CAGGTCTCAG CAGCAAGAGA TACACGGAGG AAGCCTAGCA 1960
TGCTCCTACC TGGCCTGACC TGGGTAGTAA CTAATTACAC 2000
CGTCGCTCAT CTTGAGACAG GTGGAACTCT TCAGCGTGTG 2040
CTCTTTAGTA GTGATGATGA TGATGCCTTA GCAATGACAA 2080
TTATCTCTAG TTGCTGCTTT GCTTATTGTA CACAGACAAA 2120
ATGCTTGGGT CATTCACCAC GGTCAAAGTA AGGTGTGGCT 2160
AGTATATGTG ACCTTTGATT AG                    2182
```

FIG. 21A

MET GLY LEU VAL GLY TRP GLY LEU LEU LEU
1 5 10

GLY CYS LEU GLY CYS GLY ILE LEU LEU ARG
15 20

ALA ARG ALA GLN PHE PRO ARG VAL CYS MET
25 30

THR LEU ASP GLY VAL LEU ASN LYS GLU CYS
35 40

CYS PRO PRO LEU GLY PRO GLU ALA THR ASN
45 50

ILE CYS GLY PHE LEU GLU GLY ARG GLY GLN
55 60

CYS ALA GLU VAL GLN THR ASP THR ARG PRO
65 70

TRP SER GLY PRO TYR ILE LEU ARG ASN GLN
75 80

ASP ASP ARG GLU GLN TRP PRO ARG LYS PHE
85 90

PHE ASN ARG THR CYS LYS CYS THR GLY ASN
95 100

PHE ALA GLY TYR ASN CYS GLY GLY CYS LYS
105 110

PHE GLY TRP THR GLY PRO ASP CYS ASN ARG
115 120

LYS LYS PRO ALA ILE LEU ARG ARG ASN ILE
125 130

FIG. 21B

HIS SER LEU THR ALA GLN GLU ARG GLU GLN
135 140

PHE LEU GLY ALA LEU ASP LEU ALA LYS LYS
145 150

SER ILE HIS PRO ASP TYR VAL ILE THR THR
155 160

GLN HIS TRP LEU GLY LEU LEU GLY PRO ASN
165 170

GLY THR GLN PRO GLN ILE ALA ASN CYS SER
175 180

VAL TYR ASP PHE PHE VAL TRP LEU HIS TYR
185 190

TYR SER VAL ARG ASP THR LEU LEU GLY PRO
195 200

GLY ARG PRO TYR LYS ALA ILE ASP PHE SER
205 210

HIS GLN GLY PRO ALA PHE VAL THR TRP HIS
215 220

ARG TYR HIS LEU LEU TRP LEU GLU ARG GLU
225 230

LEU GLN ARG LEU THR GLY ASN GLU SER PHE
235 240

ALA LEU PRO TYR TRP ASN PHE ALA THR GLY
245 250

LYS ASN GLU CYS ASP VAL CYS THR ASP ASP
255 260

FIG. 21C

TRP LEU GLY ALA ALA ARG GLN ASP ASP PRO
265 270

THR LEU ILE SER ARG ASN SER ARG PHE SER
275 280

THR TRP GLU ILE VAL CYS ASP SER LEU ASP
285 290

ASP TYR ASN ARG ARG VAL THR LEU CYS ASN
295 300

GLY THR THR GLU GLY LEU LEU ARG ARG ASN
305 310

LYS VAL GLY ARG ASN ASN GLU LYS LEU PRO
315 320

THR LEU LYS ASN VAL GLN ASP CYS LEU SER
325 330

LEU GLN LYS PHE ASP SER PRO PRO PHE PHE
335 340

GLN ASN SER THR PHE SER PHE ARG ASN ALA
345 350

LEU GLU GLY PHE ASP LYS ALA ASP GLY THR
355 360

LEU ASP SER GLN VAL MET ASN LEU HIS ASN
365 370

LEU ALA HIS SER PHE LEU ASN GLY THR ASN
375 380

ALA LEU PRO HIS SER ALA ALA ASN ASP PRO
385 390

FIG. 21D

```
VAL PHE VAL VAL LEU HIS SER PHE THR ASP
                395                 400

ALA ILE PHE ASP GLU TRP LEU LYS ARG ASN
                405                 410

ASN PRO SER THR ASP ALA TRP PRO GLN GLU
                415                 420

LEU ALA PRO ILE GLY HIS ASN ARG MET TYR
                425                 430

ASN MET VAL PRO PHE PHE PRO PRO VAL THR
                435                 440

ASN GLU GLU LEU PHE LEU THR ALA GLU GLN
                445                 450

LEU GLY TYR ASN TYR ALA VAL ASP LEU SER
                455                 460

GLU GLU GLU ALA PRO VAL TRP SER THR THR
                465                 470

LEU SER VAL VAL ILE GLY ILE LEU GLY ALA
                475                 480

PHE VAL LEU LEU LEU GLY LEU LEU ALA PHE
                485                 490

LEU GLN TYR ARG ARG LEU ARG LYS GLY TYR
                495                 500

ALA PRO LEU MET GLU THR GLY LEU SER SER
                505                 510

LYS ARG TYR THR GLU GLU ALA
                515
```

SEQUENCE LISTING

<110> YALE UNIVERSITY

<120> INNATE IMMUNE SYSTEM-DIRECTED VACCINES

<130> 044574-5071-WO
<140> NOT YET ASSIGNED

<141> 2001-07-31

<150> US 60/222,042
<151> 2000-07-31

<160> 13

<170> PatentIn version 3.0

<210> 1

<211> 4

<212> PRT

<213> Artificial

<220>

<223> lipidation site

<220>

<221> VARIANT

<222> (2)..(3)

<223> X=any amino acid, preferably serine

<400> 1

Cys Xaa Xaa Asn
1

<210> 2

<211> 78

<212> PRT

<213> Escherichia coli

<220>

<221> misc_feature

<223> BLP

<400> 2

Met Lys Ala Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser Thr
1 5 10 15

Leu Leu Ala Gly Cys Ser Ser Asn Ala Lys Ile Asp Gln Leu Ser Ser
20 25 30

Asp Val Gln Thr Leu Asn Ala Lys Val Asp Gln Leu Ser Asn Asp Val
35 40 45

Asn Ala Met Arg Ser Asp Val Gln Ala Ala Lys Asp Asp Ala Ala Arg
50 55 60

Ala Asn Gln Arg Leu Asp Asn Met Ala Thr Lys Tyr Arg Lys
65 70 75

<210> 3

<211> 20

<212> PRT

<213> Escherichia coli

<220>

<221> misc_feature

<223> BLP leader sequence

<400> 3

Met Lys Ala Thr Lys Leu Val Leu Gly Ala Val Ile Leu Gly Ser Thr
1 5 10 15

Leu Leu Ala Gly
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<213> Borrelia burgdorferi

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<223> Outer surface protein A

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Met Lys Lys Tyr Leu Leu Gly Ile Gly Leu Ile Leu Ala Leu Ile Ala
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<223> Ra5G ragweed pollen allergen

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Met Lys Asn Ile Phe Met Leu Thr Leu Phe Ile Leu Ile Ile Thr Ser
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Glu Asp Asp Gly Leu Cys Tyr Glu Gly Thr Asn Cys Gly Lys Val Gly
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Lys Tyr Cys Cys Ser Pro Ile Gly Lys Tyr Cys Val Cys Tyr Asp Ser
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Lys Ala Ile Cys Asn Lys Asn Cys Thr
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<223> Tyrosinase-Related Kinase Protein 2 (TRP-2)

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<222> (945)..(968)

<223> T-cell epitope

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<222> (840)..(1040)

<223> Region linked to BLP to form fusion protein

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720

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780

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1800

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1860

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1920

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2040

ctctttagta gtgatgatga tgatgcctta gcaatgacaa ttatctctag ttgctgcttt
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<211> 517

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<222> (146)..(212)

<223> Region linked to BLP to form fusion protein

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35 40 45

Thr Asn Ile Cys Gly Phe Leu Glu Gly Arg Gly Gln Cys Ala Glu Val
50 55 60

Gln Thr Asp Thr Arg Pro Trp Ser Gly Pro Tyr Ile Leu Arg Asn Gln
65 70 75 80

Asp Asp Arg Glu Gln Trp Pro Arg Lys Phe Phe Asn Arg Thr Cys Lys
85 90 95

Cys Thr Gly Asn Phe Ala Gly Tyr Asn Cys Gly Gly Cys Lys Phe Gly
100 105 110

Trp Thr Gly Pro Asp Cys Asn Arg Lys Lys Pro Ala Ile Leu Arg Arg
115 120 125

Asn Ile His Ser Leu Thr Ala Gln Glu Arg Glu Gln Phe Leu Gly Ala
130 135 140

Leu Asp Leu Ala Lys Lys Ser Ile His Pro Asp Tyr Val Ile Thr Thr
145 150 155 160

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Gln His Trp Leu Gly Leu Leu Gly Pro Asn Gly Thr Gln Pro Gln Ile
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Ala Asn Cys Ser Val Tyr Asp Phe Phe Val Trp Leu His Tyr Tyr Ser
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Val Arg Asp Thr Leu Leu Gly Pro Gly Arg Pro Tyr Lys Ala Ile Asp
        195                 200                 205

Phe Ser His Gln Gly Pro Ala Phe Val Thr Trp His Arg Tyr His Leu
    210                 215                 220

Leu Trp Leu Glu Arg Glu Leu Gln Arg Leu Thr Gly Asn Glu Ser Phe
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Ala Leu Pro Tyr Trp Asn Phe Ala Thr Gly Lys Asn Glu Cys Asp Val
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Cys Thr Asp Asp Trp Leu Gly Ala Ala Arg Gln Asp Asp Pro Thr Leu
            260                 265                 270

Ile Ser Arg Asn Ser Arg Phe Ser Thr Trp Glu Ile Val Cys Asp Ser
        275                 280                 285

Leu Asp Asp Tyr Asn Arg Arg Val Thr Leu Cys Asn Gly Thr Thr Glu
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Gly Leu Leu Arg Arg Asn Lys Val Gly Arg Asn Asn Glu Lys Leu Pro
305                 310                 315                 320

Thr Leu Lys Asn Val Gln Asp Cys Leu Ser Leu Gln Lys Phe Asp Ser
                325                 330                 335

Pro Pro Phe Phe Gln Asn Ser Thr Phe Ser Phe Arg Asn Ala Leu Glu
            340                 345                 350

Gly Phe Asp Lys Ala Asp Gly Thr Leu Asp Ser Gln Val Met Asn Leu
        355                 360                 365

His Asn Leu Ala His Ser Phe Leu Asn Gly Thr Asn Ala Leu Pro His
    370                 375                 380

Ser Ala Ala Asn Asp Pro Val Phe Val Val Leu His Ser Phe Thr Asp
385                 390                 395                 400

Ala Ile Phe Asp Glu Trp Leu Lys Arg Asn Asn Pro Ser Thr Asp Ala
                405                 410                 415

Trp Pro Gln Glu Leu Ala Pro Ile Gly His Asn Arg Met Tyr Asn Met
            420                 425                 430

Val Pro Phe Phe Pro Pro Val Thr Asn Glu Glu Leu Phe Leu Thr Ala
        435                 440                 445

Glu Gln Leu Gly Tyr Asn Tyr Ala Val Asp Leu Ser Glu Glu Glu Ala
    450                 455                 460

Pro Val Trp Ser Thr Thr Leu Ser Val Val Ile Gly Ile Leu Gly Ala
465                 470                 475                 480
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Phe Val Leu Leu Leu Gly Leu Leu Ala Phe Leu Gln Tyr Arg Arg Leu
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<211> 68

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<213> Mus musculus

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<222> (37)..(44)

<223> T-cell epitope

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<223> TRP-2

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Leu Asp Leu Ala Lys Lys Ser Ile His Pro Asp Tyr Val Ile Thr Thr
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Gln His Trp Leu Gly Leu Leu Gly Pro Asn Gly Thr Gln Pro Gln Ile
20 25 30

Ala Asn Cys Ser Val Tyr Asp Phe Phe Val Trp Leu His Tyr Tyr Ser
35 40 45

Val Arg Asp Thr Leu Leu Gly Pro Gly Arg Pro Tyr Lys Ala Ile Asp
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Phe Ser His Gln
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<210> 13

<211> 8

<212> PRT

<213> Mus musculus

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<221> SITE

<222> (1)..(8)

<223> T-cell epitope

<400> 13

Val Tyr Asp Phe Phe Val Trp Leu
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/24228

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :A61K 39/00, 39/02; C12P 21/00, 1/21

US CL : 424/184.1, 190.1, 192.1; 435/69.1, 252.3; 536/23.5

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/184.1, 190.1, 192.1; 435/69.1, 252.3; 536/23.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, MEDLINE, BIOSIS, EMBASE, SCISERACH, CAPLUS ON STN

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,601,831 A (GREEN et al) 11 February 1997 (2/11/1997), see entire document.	1-11, 16-18, 22-26, 29-31, 37-40, 43-44, 50-52, 56-58 64-69, 80 and 82-84
X	EP 0,540,128 A1 (BIOTECHNOLOGY AUSTRALIA PTY. LTD.) 05 May 1993 (05/05/93), see entire document, page 20, lines 26-48, in particular.	1-12, 16-18, 22-31, 37-40, 50 64-72, 76-78, 80 and 82-84

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

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"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search 27 SEPTEMBER 2001	Date of mailing of the international search report 16 NOV 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer PHUONG N. HUYNH Telephone No. (703) 308-0196

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/24228

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 97/06590 A1 (BIOENTERPRISES PTY. LTD.) 05 November 1987 (05.11.1987), see entire document, page 16, see claims 1-35, claims 38-42, in particular.	1-12, 16-18, 22-31, 37-40, 50, 55, 59-61, 64-72, 75-78 and 82-84
Y	NAKAMURA, K et al. DNA Sequence of the Gene for the Outer Membrane Lipoprotein of E. Coli an Extremely AT-Rich Promoter. Cell. December 1979, Vol. 18, pages 1109-1117, see page 1114, in particular.	13, 19-21 and 62
Y	MEEKER A et al. A Fusion Protein Between Serum Amyloid A and Staphylococcal Nuclease - Synthesis, Purification, and Structural Studies. Proteins. March 1998, Vol. 30 No. 4, pages 381-7, see entire document.	14, 34, 41-42, 49, 73 and 79
Y	VERMA, N et al. Delivery of class I and class II MHC-restricted T-cell epitopes of listeriolysin of Listeria monocytogenes by attenuated salmonella. Vaccine. 1995, Vol. 13, No. 2, pages 142-150, see entire document.	14-15, 34-36, 41-42, 49, 63 and 73
Y	US 5,693,495 A (BREITENEDER et al) 02 December 1997 (2.12.1997), see entire document.	32
Y	US 5,877,289 A (THORPE et al) 02 March 1999 (2.3.1999), see entire document.	33, 45-49, 53-54 and 73-74

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